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THE ORIGIN AND CORRELATION OF THE CLOVERLY CONGLOMERATE

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ABSTRACT

The Cloverly conglomerate is described and correlated with the following formations: the Blairmore conglomerate, the massive Kootenai sandstone of central Montana, the Lakota sandstone, the Beckwith conglomerate, the Ephraim conglomerate, the lower sandstone of the Dakota group of northern Colorado, the Lytle sandstone, the Purgatoire sandstone, and the "post-McElmo" conglomerate. Evidence is offered to show that the Cloverly conglomerate and its correlatives are the oldest Lower Cretaceous formations in the western interior and that they were derived from a mountainous area to the west, which was uplifted during the Sierra Nevada disturbance. Further evidence is given to show that the Kootenai coal measures of southern Alberta and central Montana are of Upper Jurassic age and are closely related to the Morrison formation.

INTRODUCTION

One of the most persistent and widespread of all the Mesozoic formations in the Rocky Mountain region is the conglomeratic sandstone of continental origin, which occurs at the base of the Lower Cretaceous series of sediments. This formation, which in different areas has been designated by many names, including the Cloverly conglomerate, the Lakota sandstone, the basal Blairmore conglomerate, and the lower sandstone of the Dakota group, can be traced from southern Alberta to southern Colorado and from the Black Hills district of South Dakota to southeastern Idaho. In the hope of gaining a better understanding of the conditions under which the formation was deposited, the writer, during part of the summer of 1934, made a study of the Cloverly conglomerate in southern Mon-

tana. Subsequently a detailed survey was made of the literature dealing with the Mesozoic stratigraphy of the western Great Plains and the Rocky Mountains. The purpose of this paper is to describe the results of these studies and to present for criticism the conclusions which have been deduced from them.

DESCRIPTION OF THE CLOVERLY CONGLOMERATE IN SOUTHERN MONTANA

The Cloverly conglomerate, which consists of a great many overlapping lenses of conglomerate, conglomeratic sandstone, and sandstone, varies in thickness from about 40 feet to over 100 feet. It is generally separated from the underlying Morrison shales by an erosional unconformity. Conformably overlying it are the red shales of the middle member of the Cloverly group.

The chert and quartzite pebbles in the conglomeratic lenses are all well rounded, no angular or subangular pebbles having been found. Since these materials are relatively stable, the pebbles must have suffered a great deal of abrasion to have acquired the roundness which now characterizes them. Hence it is believed that they were transported a considerable distance from their source before they were deposited. Some of the finer-grained sandstone lenses are channel deposits, whereas others exhibit eolian cross-bedding. This finer material, which is generally well sorted, is almost entirely composed of rounded grains of quartz. Although no individual bed in the formation can be traced for any great distance, the formation as a whole is remarkably persistent.

The size of the pebbles in the conglomeratic lenses becomes progressively smaller from the western part of the area studied toward the east. At the southern end of the Bridger Mountains, near Bozeman, the pebbles average slightly under an inch in diameter, whereas in the Pryor Mountains, southeast of Billings, they are much smaller, pebbles exceeding one-half inch in length being rare. Observations in many localities between these two points show that this change in size is gradual rather than abrupt. West of Livingston between 30 and 40 per cent of the pebbles are composed of light-colored quartzite. To the east the percentage of quartzite pebbles gradually decreases, becoming practically negligible in the Pryor Moun-

tains. Accompanying this decrease in the number of quartzite pebbles is a corresponding increase in the number of chert pebbles.

CORRELATION OF THE CLOVERLY CONGLOMERATE WITH OTHER FORMATIONS

CORRELATION FROM SOUTHERN MONTANA TO SOUTHERN ALBERTA

In the Great Falls and Lewistown coal fields of central Montana, described, respectively, by Fisher[1] and Calvert,[2] the rocks between the Ellis formation, of Jurassic age, and the Colorado shales are divided into the Morrison and the Kootenai formations. About 200 feet above the top of the Ellis formation, the equivalent of the Sundance of southern Montana, are workable coal beds, which by means of their contained fossil plants have been correlated with the Kootenai formation of Canada. Between the top of the Ellis and the base of the coal is a series of shales and thin sandstones, the lower part of which contains vertebrate remains of Morrison age and in the upper part of which are found Kootenai plant fossils. Calvert describes the Morrison-Kootenai contact in the Lewistown district as follows: "No suggestion of an unconformity was noted at either the base or the top of the Morrison. In fact, the lines of delimitation are somewhat uncertain, especially as regards the upper limit."[3] Later he says: "So far as can be ascertained the Kootenai formation rests conformably upon the Morrison formation, and the strata apparently represent an unbroken period of sedimentation from Jurassic into Lower Cretaceous time."[4]

Above the coal beds is a prominent massive gray sandstone between 160 and 190 feet thick overlain by a series of red shales and thin sandstones. This sandstone, which is cross-bedded and in places conglomeratic, is the most persistent member of the central Montana Kootenai formation. Fisher traced it from the central Montana coal fields through the Musselshell River region into the Bighorn basin, where he correlated it with the Cloverly conglomerate.[5] In

[1] C. A. Fisher, "Geology of the Great Falls Coal Field, Montana," *U.S. Geol. Surv. Bull. 356* (1909).

[2] W. R. Calvert, "Geology of the Lewistown Coal Field, Montana," *U.S. Geol. Surv. Bull. 390* (1909).

[3] *Ibid.*, p. 23. [4] *Ibid.*, p. 28.

[5] "Southern Extension of the Kootenai and Montana Coal-bearing Formations in Northern Montana," *Econ. Geol.*, Vol. III (1908), pp. 77–99.

the southern part of the Bighorn basin, where Fisher studied the Cloverly group, the conglomerate is underlain in several places by carbonaceous shales and thin coal seams containing plants identical with those of the Kootenai formation of Montana. The stratigraphy of these coal beds will be discussed later. This correlation of the Cloverly conglomerate with the prominent sandstone of the Kootenai formation of central Montana has been checked and verified by the work of Lee[6] and of Bauer and Robinson.[7] The latter two geologists also traced the formation northward from the Pryor Mountains through the Crow Indian Reservation to the Cat Creek anticline and the Little Rocky Mountains.[8] In the Cat Creek oil field it is correlated with the sand below the Cat Creek sand of the well logs.

In most Montana sections there is no coal or carbonaceous shale beneath the coarse-grained sandstone or conglomerate, the position of these beds in the stratigraphic column being occupied by varicolored shales and sandstones which have been referred to both the Kootenai and the Morrison formations. In addition to the Great Falls and Lewistown districts already mentioned, coal is reported beneath the conglomeratic sandstone by Weed in the Judith Mountains[9] and by Calvert near Gardiner, Montana.[10] In a section measured by Reeves on the south flank of the Bearpaw Mountains the sandstone is underlain by carbonaceous shales.[11] Carbonaceous shales are also reported by Condit beneath a strong conglomeratic phase of the sandstone near Indian Creek, Montana.[12]

[6] W. T. Lee, "Correlation of Geologic Formations between East-Central Colorado, Central Wyoming, and Southern Montana," *U.S. Geol. Surv. Prof. Paper 149* (1927).

[7] C. M. Bauer and E. G. Robinson, "Comparative Stratigraphy in Montana," *Amer. Assoc. Pet. Geol. Bull. 7* (1923), pp. 159–78.

[8] *Ibid.*

[9] W. H. Weed and L. V. Pirsson, "Geology and Mineral Resources of the Judith Mountains of Montana," *U.S. Geol. Surv. 18th Ann. Rept.*, Part III (1898), p. 477.

[10] "The Electric Coal Field, Park County, Montana," *U.S. Geol. Surv. Bull. 471* (1912), p. 413.

[11] F. Reeves, "Geology and Possible Oil and Gas Resources of the Faulted Area South of the Bearpaw Mountains, Montana," *U.S. Geol. Surv. Bull. 751* (1924), p. 92.

[12] D. D. Condit, "Relations of Late Paleozoic and Early Mesozoic Formations of Southwestern Montana and Adjacent Parts of Wyoming," *U.S. Geol. Surv. Prof. Paper 120* (1918), p. 115.

No definite unconformity separating the coal beds and carbonaceous shales from the conglomeratic sandstone has been described in Montana. Lee, however, describes the relationships in the vicinity of Belt, Montana, thus:

> On the other hand, the irregularity in thickness of the coal-bearing rocks and the absence in some places of coal beds suggest erosion, which removed some of the coal-bearing rocks prior to the deposition of the overlying beds. This suggestion of erosion is in harmony with the evidence of erosion that removed the coal-bearing rocks from many of the localities in the Big Horn Basin here described before the deposition of the conglomeratic sandstone of the lower part of the Cloverly formation.[13]

In summing up the stratigraphic relationships of the conglomeratic sandstone in Montana, the following generalizations can be made. Every described Lower Cretaceous section for Montana exhibits a prominent sandstone separating shales, which differs from the other sandstones of the region in that it is thick, massive, eolian cross-bedded, generally conglomeratic, and in places contains petrified wood. This sandstone is very persistent, having been successfully traced along the outcrop whenever attempted. No remains of Morrison dinosaurs are found above it, whereas they are generally found in the underlying shales. Although the sandstone is locally underlain by coal beds and carbonaceous shales, it is everywhere overlain by reddish shales. This indicates that widespread swamp conditions ended with the deposition of the coarse clastic material. In some places the conglomeratic sandstone is separated from the underlying shales by a definite erosional unconformity. In other places, where no definite unconformity has been described beneath the sandstone, the stratigraphic relationships existing between the sandstone and the underlying rocks suggest erosion. For these reasons it seems to the writer that the base of the sandstone represents a change in the conditions of sedimentation sufficiently important to mark at least a formational boundary.

In southwestern Alberta the stratigraphy is somewhat similar to that of central Montana. In the disturbed belt of southwestern Alberta, Stewart divides the strata lying between the Fernie shales, which are equivalent to the Ellis formation, and the Benton shales

[13] *Op. cit.*, p. 67.

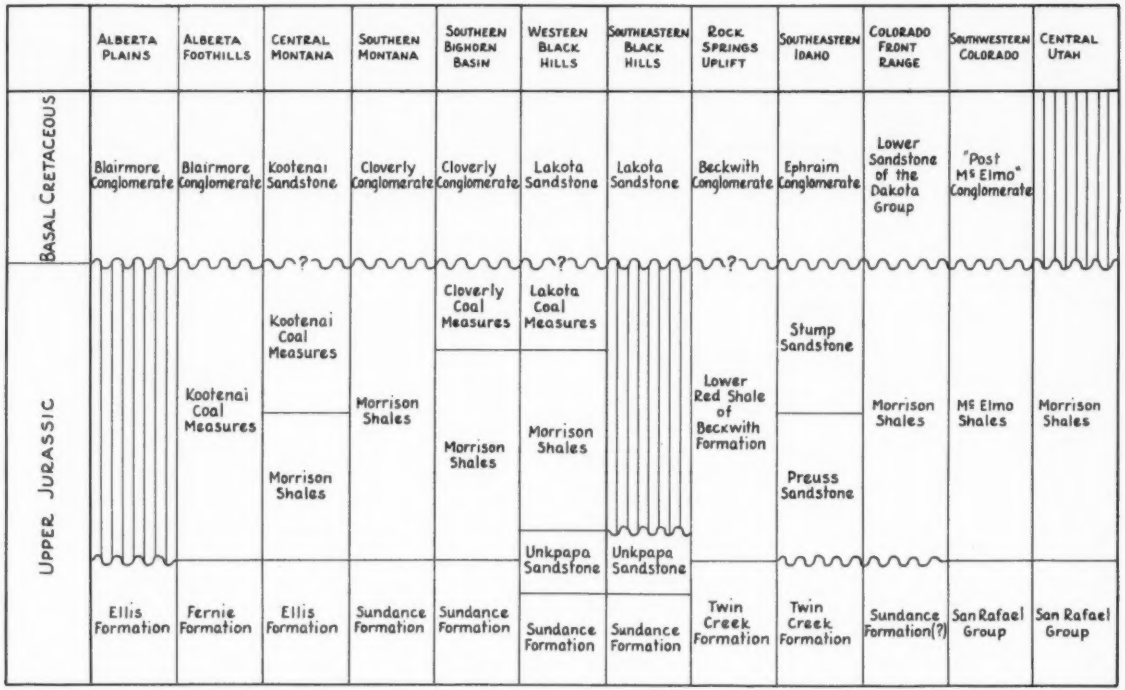


FIG. 1.—Tentative correlation of the Upper Jurassic and basal Lower Cretaceous formations in the western interior. Wavy lines indicate unconformities. Ruled vertical lines indicate that formations are missing.

of Colorado age into the Kootenai and Blairmore formations.[14] The Morrison formation has not been recognized in Alberta. Stewart says of the Fernie-Kootenai contact:

> In the Blairmore and Southfork coal areas described, respectively, by Leach and MacKenzie, the Kootenay formation rests conformably on the Fernie shales of later Jurassic age. The passage of the one formation to the other is thought to be transitional in character, and the position of the dividing line between them is somewhat indefinite.[15]

The Kootenai formation consists of coal seams interbedded with sandstones and shales. Most of the coal beds occur in the upper part of the formation. The Blairmore formation, which lies above the Kootenai coal measures, has at its base a thick cherty conglomerate. Stewart describes this member:

> The thick cherty conglomerate forming the basal member of the formation is the best horizon marker in the foothills. It is very persistent and has been used as a guide from the Castle River northward to the Bow, a distance of about 120 miles. The conglomerate is made up of well rounded pebbles of black, white, and greenish chert, set in a hard siliceous matrix. . . .[16]
>
> The wide geographical distribution of the basal conglomerate indicates some change in the topography or climate or both at the time it was laid down, which greatly increased the transporting power of the streams; and the relation of the conglomerate to the uppermost coal seam of the Kootenay seems to imply previous erosion of the Kootenay formation.[17]

Above the conglomerate the Blairmore formation is composed of thin sandstones and red shales. Both the Blairmore and Kootenai formations become thicker and coarser to the west.

In 1931 there appeared in the *Bulletin* of the American Association of Petroleum Geologists a symposium on the stratigraphy of the plains of southern Alberta. In his article, "Correlation and Nomenclature in Alberta," Irwin says:

> Information derived from the records of recently drilled wells has led certain contributors to the symposium to conclude that, in the southern plains of Alberta, all the strata included between the Ellis formation and the Colorado shale are correlative with the Blairmore formation of the Alberta foothills. . . . .
>
> The base of the Blairmore formation is marked by a conglomerate bed which

[14] J. S. Stewart, "Geology of the Disturbed Belt of Southwestern Alberta," *Can. Geol. Surv. Mem. 112* (1919).

[15] *Ibid.*, p. 26. [16] *Ibid.*, p. 28. [17] *Ibid.*, p. 30.

occurs in a large part of the Alberta foothills province and has now been recognized in deep wells on the plains by W. S. Yarwood and P. D. Moore.[18]

From the foregoing descriptions it is obvious that the conglomerate at the base of the Blairmore formation of Alberta not only occupies the same stratigraphic position as the prominent sandstone in the Kootenai formation of central Montana but is lithologically similar to the Cloverly conglomerate of southern Montana, with which the prominent sandstone of the Montana Kootenai formation has been correlated. Both the Blairmore conglomerate of Alberta and the Kootenai sandstone of Montana lie above the uppermost coal seam of the Kootenai coal measures, and both are overlain by thin sandstones and red shales. Hence the writer firmly believes that the cherty conglomerate at the base of the Blairmore formation in Alberta, the prominent coarse-grained sandstone overlying the Kootenai coal beds in central Montana, and the conglomerate at the base of the Cloverly group in southern Montana are stratigraphic equivalents and are of essentially the same age.

CORRELATION FROM THE BIGHORN BASIN TO THE BLACK HILLS

The Cloverly conglomerate of the Bighorn basin is similar to that of the Pryor Mountains in both thickness and lithology. It is generally separated from the underlying Morrison formation by an erosional unconformity and is overlain by the red shales forming the middle member of the Cloverly group. In several places in the southern part of the Bighorn basin the conglomeratic sandstone is underlain by thin coal seams and carbonaceous shales. It was these coal beds that Fisher correlated with the Kootenai coal measures of the Great Falls coal field.[19] During 1922 Lee made a detailed field study of these rocks and measured several well-exposed sections.[20] In most of these sections he noted an erosional unconformity between the conglomeratic sandstone and the coal-bearing strata beneath it. In a few sections the carbonaceous shales and coal beds are separated from the Morrison shales by a brown conglomerate, but this

[18] J. S. Irwin, *Amer. Assoc. Petrol. Geol. Bull. 15* (1931), p. 1132.

[19] "Southern Extension of the Kootenai and Montana Coal-bearing Formations in Northern Montana," *op. cit.*

[20] *Op. cit.*, pp. 57–62, Pl. II.

conglomerate is known to be of local occurrence, for in other sections carbonaceous shales directly overlie the reddish shales of the Morrison formation.

Along the eastern front of the Bighorn Mountains the basal member of the Cloverly group is thinner and much finer grained. In descriptions by Darton of several localities no mention is made of any conglomeratic lenses in the formation.[21] Otherwise the stratigraphy of the Cloverly group and the underlying rocks in the Bighorn Range is the same as in the Bighorn basin.

Darton divides the rocks of the Black Hills region lying between the Sundance formation and the Graneros shale, which contains marine fossils of Colorado age, into the following formations: the Unkpapa sandstone, the Morrison shales, the Lakota sandstone, the Minnewaste limestone, the Fuson shales, and the Dakota sandstone.[22] Of these formations, the Unkpapa is the oldest and the Dakota is the youngest. The Unkpapa sandstone, which conformably overlies the Sundance shales and is in turn conformably overlain by the Morrison formation, is a fine-grained sandstone of very even texture. It probably was deposited in the littoral zone by the retreating Sundance sea.

As typically developed in the Black Hills, the Lakota formation consists of from 30 to 80 feet of sandstone with a few conglomeratic streaks near the base. In the northwestern part of the Black Hills region this cliff-forming sandstone is underlain locally by a sequence of carbonaceous shale, coal, and thin sandstones. These coal measures, which Darton includes in the Lakota formation, are conformably underlain by typical Morrison shales containing a dinosaur fauna. Since these coal-bearing beds are not everywhere present between the reddish shales of the Morrison formation and the massive Lakota sandstone and since they do not occur beneath the sandstone in the southeastern part of the uplift where it overlaps the Morrison formation onto the Unkpapa sandstone, it seems to the

[21] N. H. Darton, "Geology of the Bighorn Mountains," *U.S. Geol. Surv. Prof. Paper 51* (1906), p. 51.

[22] "Geology and Water Resources of the Northern Portion of the Black Hills and Adjoining Regions in South Dakota and Wyoming," *U.S. Geol. Surv. Prof. Paper 65* (1909), pp. 37–51.

writer that stratigraphically they are more closely related to the Morrison formation than to the Lakota.

In the northern portion of the Black Hills the Lakota sandstone is overlain by reddish clays and shales of the Fuson formation. Farther south it is separated from the Fuson shales by the Minnewaste limestone, a thin fresh-water deposit of limited extent, which also occurs in the Hartville uplift to the southwest.

In summary, the writer agrees with Darton, who mapped both the Black Hills and the Bighorn Range, in correlating the Lakota sandstone of the Black Hills with the Cloverly conglomerate to the west and the Fuson shale with the reddish shales forming the middle member of the Cloverly group of the Bighorn Range.[23] He would also correlate the coal measures below the Lakota sandstone in the northwestern part of the Black Hills region with the coal-bearing strata underlying the Cloverly conglomerate in the southern Bighorn basin and with the Kootenai coal measures of central Montana.

CORRELATION FROM THE LARAMIE MOUNTAINS TO SOUTHEASTERN IDAHO

Lee measured four sections of the Cloverly group on the eastern side of the Laramie Range in southern Wyoming.[24] In two of these sections the basal member is described as a sandstone which is conglomeratic near the base. In the other two no conglomeratic streaks are reported. In every case the coarse sandstone overlies the variegated Morrison shales, which separate it from the Sundance formation, and is conformably overlain by the middle Cloverly shales. Lee also studied the Cloverly group in the Laramie basin, the Hanna basin, and in the vicinity of Rawlins, Wyoming.[25] The basal member gradually becomes coarser to the west, being described near Rawlins as a thick, resistant conglomerate.

About 100 miles southwest of Rawlins on the northern flank of the Uinta Range, A. R. Schultz groups all the rocks lying between the Twin Creek limestone, which is equivalent to the Sundance formation, and the Aspen shale of Colorado age into the Beckwith formation. He describes this formation as follows:

[23] "Geology of the Bighorn Mountains," *op. cit.*, p. 53.

[24] *Op. cit.*, pp. 40–43.

[25] *Ibid.*, pp. 67–73.

Along the north side of the Uinta Mountains the Beckwith formation consists of four rather distinct members. Directly below the Aspen shale is a fine-grained brown to gray quartzitic sandstone and sandy shale with some conglomerate or conglomeratic sand. This sandstone is considered by the writer equivalent to the upper part of the Beckwith formation of western Wyoming and to beds occuring elsewhere in this part of the Rocky Mountain States that are mapped as the Dakota.[26]

The second and fourth (lowest) members of the Beckwith are very much alike and lithologically resemble the Morrison of Wyoming. These rocks consist of indurated clays of dark greenish cast, together with some shaly sandstone beds, white clays, and clays of mottled colors such as green, purple, maroon, gray, red, and pink. The two members are separated by a conglomeratic sandstone member which in places is from 150 to 200 feet thick; the shale above it is approximately one-fourth to one-third as thick as the lowest member. The entire group of four members, which are probably in part unconformable, is about 850 feet thick on the north side of the Uinta Mountains, in the Henrys Fork field, and in the Vermillion Creek area.[27]

In referring to the oil possibilities of the Baxter basin and the Rock Springs uplift, Schultz says:

The conglomerate member of the Beckwith is the only member below the upper sandstone that may serve as a reservoir for the accumulation of oil in this part of Wyoming. In the opinion of the writer it is probably equivalent to the basal conglomeratic sandstone of the Cloverly formation of the Big Horn Mountains, the lower member of the Cloverly formation of the Basin and Greybull oil and gas fields, and the Dakota(?) of the Salt Creek field, and is identical with the conglomerate described as of Lower Cretaceous age(?) in the Lander field.[28]

West of the Rock Springs uplift the Beckwith formation rapidly grows thicker and coarser. In northwestern Uinta County, Wyoming, near the Utah state line, it exceeds 5,000 feet in thickness.[29] In this part of Wyoming the Beckwith formation contains marine Jurassic fossils in its lower part.[30] This occurrence furnishes an excellent check on Schultz's correlation of the lower member of the Beckwith formation with the Morrison shales, which was based

[26] A. R. Schultz, "Oil Possibilities in and around Baxter Basin, in the Rock Springs Uplift, Sweetwater County, Wyoming," *U.S. Geol. Surv. Bull. 702* (1920), p. 75.

[27] *Ibid.*, p. 76.

[28] *Ibid.*, pp. 76–77.

[29] A. C. Veatch, "Geography and Geology of a Portion of Southwestern Wyoming," *U.S. Geol. Surv. Prof. Paper 56* (1907), p. 57.

[30] *Ibid.*, pp. 57–58.

solely on lithology and stratigraphic position. In 1936, sixteen years after Schultz made this correlation, Crickmay described a thin widespread horizon in the Morrison formation which contains a recurrent Sundance fauna:

> The Morrison formation, long regarded as probably Lower Cretaceous, proves to be definitely of Upper Jurassic age, for it contains, even though only in a single thin bed about the middle of its thickness, marine species common to the Sundance.[31]

In southeastern Idaho, less than 100 miles northwest of the type locality of the Beckwith formation, the Twin Creek limestone is unconformably overlain by nearly 1,000 feet of nonmarine sandstones and sandy shales, the Preuss formation. Conformably above these beds lies the Stump sandstone, which has at its base a relatively thin layer of grit containing marine fossils common to the Twin Creek formation. The remainder of this formation, which ranges in thickness between 200 and 600 feet, is nonfossiliferous. Mansfield, who mapped this section of Idaho, correlates the Preuss and Stump formations with the lower part of the Beckwith formation of western Wyoming.[32]

Overlying the Stump sandstone in southeastern Idaho is the Ephraim conglomerate, which is described by Mansfield thus:

> The rock is a red conglomerate that contains minor amounts of sandstone and some thin bands of gray to purplish limestone, some of which is nodular. It is about 1,000 feet thick at the type locality, but differs much in thickness and character, becoming in some regions practically all conglomerate, the pebbles in which range in size from less than 1 inch to nearly a foot in diameter. The pebbles represent a wide variety of materials, including quartzite, limestone, and chert, probably derived from Carboniferous or early Paleozoic formations, the Woodside and Thaynes formations, and perhaps even from the Nugget sandstone. The pebbles are mostly smooth and subangular and some are even well rounded. A few of the large pieces are angular.[33]

Mansfield correlates this conglomerate with the conglomerate beds of the Beckwith formation and with the conglomeratic sandstone of the Montana Kootenai formation.[34]

[31] C. H. Crickmay, "Study in the Jurassic of Wyoming," *Bull. Geol. Soc. Amer.*, Vol. XLVII (1936), p. 555.

[32] G. R. Mansfield, "Geography, Geology, and Mineral Resources of Part of Southeastern Idaho," *U.S. Geol. Surv. Prof. Paper 152* (1927), pp. 99–101.

[33] *Ibid.*, p. 103.

[34] *Ibid.*, pp. 103–4, 377.

In summing up the stratigraphic relationships of the Jurassic and Lower Cretaceous rocks in Wyoming, northern Utah, and southeastern Idaho the following generalizations can be made. During the Upper Jurassic there were two incursions of the sea into this area. The second of these was very short, being represented in the stratigraphic column by only a few very thin beds in the Stump, lower Beckwith, and Morrison formations. The break between the Jurassic and the Lower Cretaceous periods is everywhere recorded by a marked change in the type of sedimentation and in some places by an erosional unconformity. The conglomerates and coarse-grained sandstones, which represent the beginning of Lower Cretaceous sedimentation, become decidedly thicker and coarser to the west.

CORRELATION FROM THE LARAMIE MOUNTAINS TO SOUTHERN COLORADO

Lee traced the conglomeratic sandstone at the base of the Cloverly group from the Laramie Range southward along the Rocky Mountain front to the foothills in the vicinity of Colorado Springs, Colorado.[35] Over this distance it is very persistent, occurring above the Morrison shales wherever they outcrop. The sandstone is separated from the Morrison formation by a conspicuous erosional unconformity and is everywhere conformably overlain by a series of variegated shales. In most places the formation is described as a coarse-grained sandstone with conglomeratic streaks near its base.

In northern Colorado the conglomeratic sandstone and the overlying shales are known as the lower sandstone and the lower shale of the Dakota group. Near Colorado Springs the sandstone is called the Lytle sandstone and the overlying shales are known as the Glencairn shale. In southern Colorado, south of Colorado Springs, the Lytle sandstone and the Glencairn shale are grouped together to form the Purgatoire formation.

CORRELATIONS IN SOUTHWESTERN COLORADO AND CENTRAL UTAH

In 1921 the Colorado Geological Survey mapped a portion of southwestern Colorado in connection with the exploitation of the carnotite deposits of the region.[36] Since all the carnotite is con-

[35] *Op. cit.*, pp. 25–44.

[36] R. C. Coffin, "Radium, Uranium, and Vanadium Deposits of Southwestern Colorado," *Colo. Geol. Surv. Bull. 16* (1921).

tained in the McElmo formation, which is equivalent to the Morrison shales, especial attention was paid to the stratigraphy of the McElmo and associated formations.

The beds lying between the McElmo formation and the Mancos shale of Colorado age are divided in southwestern Colorado into the "post-McElmo" and Dakota formations. Unconformably overlying the shales and thin sandstones of the McElmo is a massive conglomerate containing pebbles of quartzite and dark chert, some of which exceed 2 inches in diameter. This conglomerate forms the basal member of the "post-McElmo" formation.

The "post-McElmo" formation varies irregularly in thickness from about 25 feet to over 200 feet. Where it is fully developed, the conglomerate is conformably overlain by cherty limestones of freshwater origin, reddish shales, and thin sandstone lenses, whereas in those places where the formation is thin only the conglomerate member is present. The Dakota sandstone, which lies unconformably above the "post-McElmo" formation, is known to be the basal sandstone of the Colorado group, for it grades upward into the fossiliferous marine shales deposited in the Colorado sea. In the opinion of the writer the "post-McElmo" formation is equivalent to the lower sandstone and the lower shale of the Dakota group of central and northern Colorado.

In northern Utah the Beckwith formation separates the Twin Creek limestone from the fossiliferous marine Upper Cretaceous deposits. In southern and central Utah, however, the Morrison, which has been correlated with the lower part of the Beckwith formation, is directly overlain by the Dakota sandstone, the Lower Cretaceous strata with which this paper is primarily concerned being absent.

SOURCE OF THE PEBBLES IN THE CONGLOMERATE

POSSIBLE SOURCES

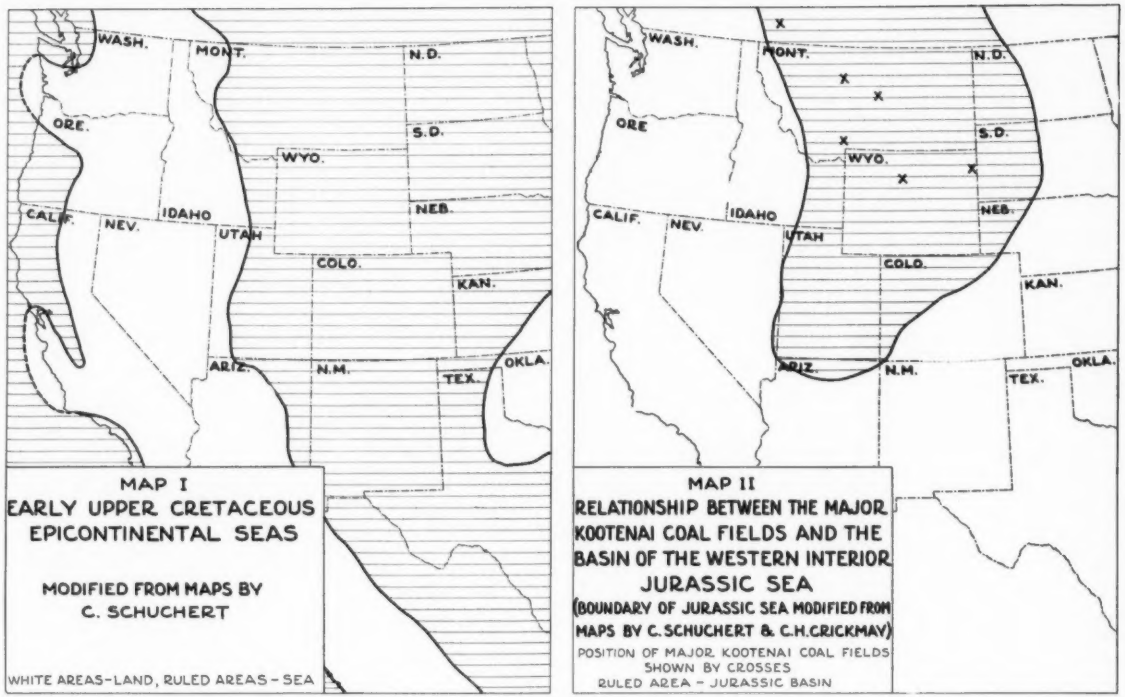
From the petrology of the Cloverly conglomerate and its equivalents it is evident that the source of the pebbles in the formation was a region of sedimentary rocks. The size of the pebbles indicates that they came from a highland region. Furthermore the fact that the conglomerates and conglomeratic sandstones are nearly everywhere underlain by fine-grained shales and are separated from these

shales in many places by an erosional unconformity indicates that the highlands or mountains, which supplied the pebbles, were uplifted just before the conglomerates and sandstones were deposited.

The Upper Cretaceous sea, which spread over the western United States, was an epicontinental sea and hence must have advanced over a land area of low relief. It is unlikely that this area could have been extensively uplifted in late Jurassic or early Cretaceous time and then have been peneplained before the beginning of the Upper Cretaceous period. The maximum extent of the Upper Cretaceous sea, as far as can be told from the present outcrops of the sediments deposited in it, is shown on Map I (Fig. 2). A study of this map will indicate that the uplift, which preceded the deposition of the conglomerates and sandstones, must have been located either in the Mississippi Valley or along the Pacific Coast. The rocks of the former region have been little disturbed since their deposition and thus the possibility of an extensive uplift there can be eliminated. There was an extensive uplift, however, along the Pacific Coast at the end of the Jurassic period. This uplift, which is known as the Sierra Nevada disturbance or the Jurasside revolution, was accompanied by mountain-building on a large scale and the intrusion of enormous batholithic masses. It is not believed that all the Pacific Coast strata were deformed at this time, but they must have been uplifted considerably when local areas were deformed.

EVIDENCE AS TO SOURCE FROM LATERAL VARIATIONS IN THE FORMATION

In the eastern portion of their area of deposition the Cloverly conglomerate and its equivalents are relatively fine grained, being described as sandstones, conglomeratic sandstones, and pebbly sandstones, whereas to the west, in western Alberta, western Montana, western Wyoming, southeastern Idaho, northern Utah, and southwestern Colorado, they are described as massive conglomerates in which individual pebbles exceed 1½ inches in diameter. In southeastern Idaho the pebbles consist of limestone, quartzite, chert, and jasper. Elsewhere no limestone pebbles are reported. Of these four rock types, limestone is the least durable, being relatively soluble and easily abraded, and consequently should be found chiefly near the source. With the exception of southeastern Idaho, where some


WASH.
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IDAHO
NEB.
UTAH
COLO.
KAN.
ARIZ.
N.M.
TEX.
OKLA.
MAP I
EARLY UPPER CRETACEOUS EPICONTINENTAL SEAS
MODIFIED FROM MAPS BY C. SCHUCHERT
WHITE AREAS-LAND, RULED AREAS-SEA
MAP II
RELATIONSHIP BETWEEN THE MAJOR KOOTENAI COAL FIELDS AND THE BASIN OF THE WESTERN INTERIOR JURASSIC SEA
(BOUNDARY OF JURASSIC SEA MODIFIED FROM MAPS BY C. SCHUCHERT & C.H. CRICKMAY)
POSITION OF MAJOR KOOTENAI COAL FIELDS SHOWN BY CROSSES
RULED AREA - JURASSIC BASIN

FIG. 2

of the larger fragments are angular, the pebbles are reported to be everywhere well rounded. All these observations indicate a western source for the pebbles.

THE AGE OF THE CONGLOMERATE

STRUCTURAL AND STRATIGRAPHIC EVIDENCE

It is generally conceded that geological periods are closed by orogenic or epeirogenic disturbances. The writer believes that these crustal movements are reflected in the sediments of neighboring regions. The Sierra Nevada disturbance closed the Jurassic period. The first sharp break in sedimentation after the retreat of the Jurassic sea from the Cordilleran geosyncline occurs at the base of the Cloverly conglomerate and its equivalents. There are no widespread coarse clastics between these conglomerates and sandstones and the sediments deposited in this sea. Hence, it is believed that the Cloverly conglomerate and the formations with which it has been correlated represent the first effect of the Jurasside revolution and that they are the earliest Lower Cretaceous formations in the Rocky Mountains and the Great Plains. If this statement regarding the age of these coarse clastic deposits is to be accepted, however, the Kootenai coal measures lying below them would have to be considered Jurassic in age.

The Morrison shales of undoubted Jurassic age are conformably overlain in central Montana by the Kootenai coal measures. In parts of the Bighorn basin and in the northwest portion of the Black Hills they are overlain conformably by carbonaceous shales and coal beds which have been correlated with the Kootenai. Where these two formations are in contact with one another there is no definite boundary separating them in every case. In some places the boundary is placed between shales having a vertebrate fauna and shales containing plant remains. In others the boundary separates gray carbonaceous shales from reddish shales. North of the Great Falls district, where the Morrison formation has not been recognized, the Kootenai formation grades imperceptibly downward into the Fernie shales, which were deposited in the northern part of the Jurassic sea. One likely interpretation of these relationships is

that the Kootenai coal measures and the Morrison shales are essentially equivalent in age and are but different facies of a single formation.

The general conditions under which the Kootenai coal measures and the Morrison shales were deposited are almost identical. Widespread coal seams such as are found in the Kootenai formation are generally conceded to have been formed in lowland swamps near sea-level. There must also have been swamps and lakes where the Morrison was deposited, for about half the dinosaurs found in these shales belong to the Sauropoda. Lull says of this group:

> The size, lightness of the vertebral column, especially the neck, the compressed and powerful tail, the incomplete articulation of the limbs, such as are never found in terrestrial animals today, and the position of the external nostrils on the top of the head all point to an amphibious if not an exclusively aquatic habitat.[37]

The chief difference between the two formations seems to be that one was deposited in a swampy region to the north, where conditions were suitable for the accumulation and preservation of plant material, and the other was deposited in a swampy flood plain farther south, where remains of vertebrates were preserved.

The geographic distribution of the Kootenai coal measures offers further evidence of a Jurassic age. Map II (Fig. 2) shows the relationship between the area covered by the western interior Jurassic sea and the major Kootenai coal basins. Since this sea advanced southward from the Arctic, it is probable that it was deeper to the north and that after it had retreated the northern part of its former basin remained closer to sea-level than the southern part. Hence if coal swamps were developed after the retreat of the Jurassic sea, one would expect them to be best developed in the northern part of its former basin. From the map it can be seen that the Kootenai coal fields are intimately associated with the northern part of the Jurassic basin. On the other hand, most of them are located over 100 miles from the nearest outcrops of Lower Cretaceous marine strata.

[37] R. S. Lull, "Sauropoda and Stegosauria of the Morrison of North America Compared with those of Europe and Eastern Africa," *Bull. Geol. Soc. Amer.*, Vol. XXVI (1915), p. 324.

PALEONTOLOGICAL EVIDENCE

The Cloverly conglomerate and its equivalents lie above the Morrison, Stump, and Lower Beckwith formations, all of which contain marine fossils of middle Upper Jurassic age. The upper shales of the Purgatoire formation of southeastern Colorado, the basal member of which has been correlated with the Cloverly conglomerate, contains a marine Comanchean fauna. Thus, according to invertebrate paleontological evidence, the conglomerates and sandstones can be placed in either the Jurassic or the Lower Cretaceous.

In Alberta, Montana, and Wyoming the conglomerates and sandstones overlie coal beds containing plant fossils referred to the Lower Cretaceous. In central Montana the Kootenai sandstone, which is continuous with the Cloverly conglomerate of southern Montana, is overlain by a series of red shales and thin sandstones which also contains Lower Cretaceous plant remains. Hence, if paleobotanical evidence is to be accepted, the conglomerates and sandstones cannot be the earliest Lower Cretaceous deposits as was indicated above. After discussing this discrepancy between the paleobotanical and the structural and stratigraphic evidence with the writer, Professor Erling Dorf, of Princeton University, kindly offered to review the correlation and age of the Kootenai flora. He concluded:

> In my opinion the floras from the so-called Kootenai of the Great Falls region are clearly separable into two clearly defined units. The lower flora, found in association with the coal beds below the massive sandstone, is most probably of Upper Jurassic age. The upper flora, from above the massive sandstone, is quite clearly Lower Cretaceous.[38]

This conclusion agrees with the writer's structural and stratigraphic evidence in placing the Kootenai sandstone, which is equivalent to the Cloverly conglomerate, at the base of the Lower Cretaceous.

CONCLUSION

As a result of these studies the writer offers the following conclusions for criticism.

1. The Cloverly conglomerate of Montana and Wyoming may be correlated with the Blairmore conglomerate of Alberta, the massive

[38] Personal communication.

Kootenai sandstone of central Montana, the Lakota sandstone of the Black Hills, the Beckwith conglomerate of Wyoming and northern Utah, the Ephraim conglomerate of southeastern Idaho, the lower sandstone of the Dakota group in northern Colorado, the Lytle sandstone of central Colorado, the Purgatoire sandstone of southern Colorado, and the "post-McElmo" conglomerate of southwestern Colorado.

2. The Cloverly conglomerate and its correlatives were derived from a highland area to the west, which was uplifted during the Sierra Nevada disturbance.

3. The Cloverly conglomerate and its correlatives are the oldest Lower Cretaceous strata in the Rocky Mountains and the Great Plains.

4. The coal measures underlying the conglomerates and sandstones in Alberta, Montana, and Wyoming are of Upper Jurassic age and are closely related to the Morrison formation.

ACKNOWLEDGMENTS.—The writer is especially indebted to Dr. R. T. Chamberlin, under whose supervision this study was made, and to Dr. W. T. Thom, Jr., who offered many valuable suggestions throughout the course of the work. The writer is also greatly indebted to Dr. Erling Dorf, who generously offered to review the correlation and age of the Kootenai flora. Drs. J. H. Bretz, R. T. Chamberlin, M. H. Stow, and W. T. Thom, Jr., were kind enough to read and criticize the manuscript. Able assistance in the field was rendered by Mr. Charles MacClintock.

THE MIOCENE HUMBOLDT FORMATION IN NORTHEASTERN NEVADA

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ABSTRACT

The Humboldt formation of northeastern Nevada consists of 5,800 feet of continental deposits which range in grain size from coarse fanglomerate to fine shale and in composition from lake deposits of limestone and oil shale to stream-laid conglomerate, sandstone, and mudstone interbedded with fine pyroclastics of water-laid and air-borne types. These beds may be divided into three members: (1) a lower member, mostly lake beds; (2) a middle member characterized by ash and tuff beds; (3) an upper member, mostly stream-laid deposits. Vertebrate and plant remains indicate a late Miocene age and an environment more humid than the present.

The formation occupies basins separated by northward-trending fault-block mountains. It was originally deposited in a large irregular depression or a series of connected intermontane basins, which have become basins of sedimentation through warping or faulting. In the area considered, some of the basin and mountain blocks have been outlined by faulting during deposition of the Humboldt beds, and that fault pattern has been perpetuated by movements continuing to the present.

INTRODUCTION

This paper presents data on Miocene basin deposits in northeastern Nevada known as the "Humboldt formation." Since these deposits may have originally covered an area conservatively estimated at 40,000 square miles, it is obvious that the 2,000 square miles considered here are only a small part of the whole and that a number of years will be required to make a complete study. For that reason many problems associated with the broader physiographic relations of Humboldt time remain unsolved.

GEOGRAPHIC RELATIONS

The center of the area covered by these Miocene deposits lies in the vicinity of Elko and the Ruby–East Humboldt Range[1] in Elko County, northeastern Nevada. Elko is located at 115°47′ W. Long. and 40°50′ N. Lat., 200 miles west of Salt Lake City, Utah. Figure 1 shows in rough outline the areal extent of the Tertiary basin deposits in northeastern Nevada. All these deposits do not necessarily belong

[1] Not to be confused with the Humboldt Range of west-central Nevada, 150 miles farther west, studied by G. D. Louderback, *Bull. Geol. Soc. Amer.*, Vol. XV (1904), pp. 298–364.

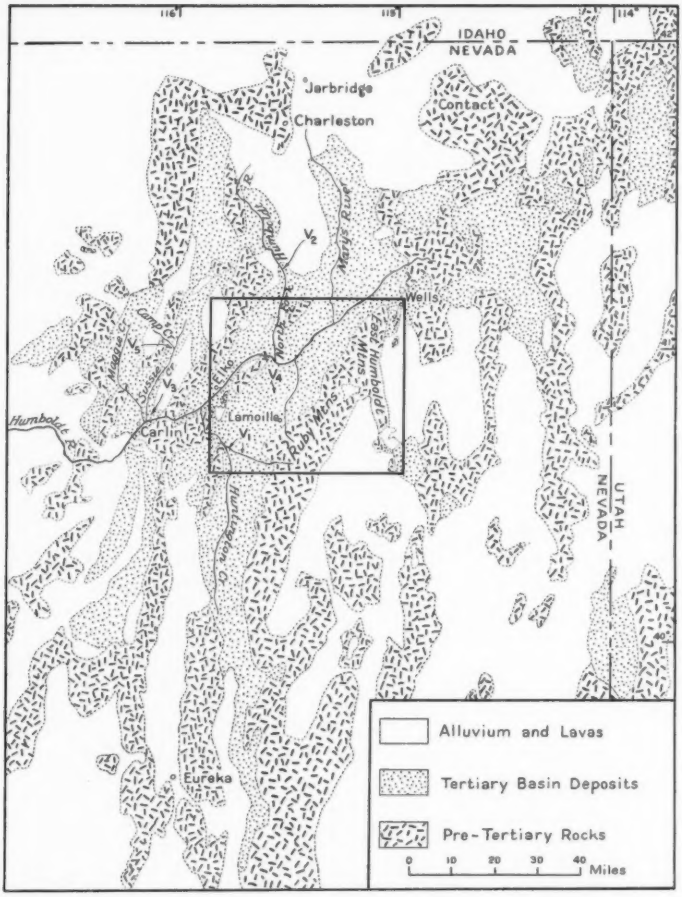

FIG. 1.—Map showing distribution of Tertiary basin deposits in northeastern Nevada, modified from the U.S. Geological Survey map of the United States (1933). The rectangle in the center represents the area here considered. (Figure 9 shows this area on a larger scale and in greater detail.) Vertebrate-fossil localities referred to in the text are shown by V_1–V_5.

to the same formation, although it seems likely that they are closely related.

PREVIOUS WORK

King[2] and his associates first described these beds in 1877–78. King divided the basin deposits in the vicinity of Elko and the Ruby–East Humboldt Range into an Eocene and a Pliocene group. The Eocene group was correlated with the Green River formation of Utah and Colorado, and the Pliocene deposits were named the "Humboldt group." Fish and plant remains were reported from the Eocene beds; and a small vertebrate fauna, thought to be of Pliocene age, was collected from the Humboldt group at Bone Valley on the North Fork of the Humboldt River. Evidence will be presented which shows that both the Eocene and Pliocene beds described by King are parts of the same formation, which is of Miocene age.

In 1914 Merriam[3] described a small vertebrate fauna from the McKnight Ranch on the North Fork of the Humboldt River. He concluded that the fauna indicated a stage in the latter half of the Miocene. Merriam pointed out that the McKnight locality is the same stratigraphically, if not geographically, as King's "Bone Valley" site. This site furnished the fauna on the basis of which King assigned a Pliocene age to the Humboldt group.

Winchester[4] discussed the oil shale in the basin deposits near Elko, which he referred to the Green River formation. In a footnote,[5] however, Winchester reports that J. P. Buwalda has discovered a Middle or Upper Miocene vertebrate fauna in beds equivalent to the oil shale, showing that they are not to be correlated with the Eocene Green River formation.

FORMATION NAME

Various names have been applied to the Tertiary basin deposits of the Elko region. This confusion has been caused largely by the fact

[2] Clarence King, "Geological Exploration of the Fortieth Parallel," *Prof. Paper 18, Engineer. Dept., U.S. Army*, Vol. I (1878), pp. 392–93, 438–39, and Vol. II (1877), p. 540.

[3] J. C. Merriam, "The Occurrence of Tertiary Mammalian Remains in Northeastern Nevada," *Univ. Calif. Pub. Dept. Geol.*, Vol. VIII (1914), pp. 275–81.

[4] Dean E. Winchester, "Oil Shale of the Rocky Mountain Region," *U.S. Geol. Surv. Bull. 729* (1923), pp. 91–102.

[5] *Ibid.*, p. 91.

that King described what he thought were both Pliocene and Eocene beds. Data will be presented in the following pages to show that only one formation is present. This will be called the "Humboldt formation." It includes the "Humboldt group," as originally defined by King, and the so-called "Eocene deposits," which had erroneously been correlated with the Green River formation of Utah and Colorado. The Humboldt formation, as here defined, consists of beds deposited chiefly in the late Miocene and possibly in the early Pliocene. It is suggested that the section of these beds exposed along Huntington Creek, a tributary of the South Fork of the Humboldt River, should be taken as the type section. The Lake Lahontan beds (Quaternary)[6] of western Nevada should not be included in this formation. Schmitt[7] has used the name "Humboldt formation" tentatively for some Pennsylvanian beds of New Mexico, but the usage advocated in the present article has priority.

LITHOLOGY OF DEPOSITS

The Humboldt formation consists of continental deposits of fluviatile and lacustrine origin, including fanglomerate, conglomerate, sandstone, mudstone, siltstone, shale, lignite, oil shale, diatomite, limy shale, limestone, and rhyolitic tuff and ash beds. A few thin rhyolite flows are interbedded in the formation on the flanks of the East Humboldt Mountains. Conglomerate, sandstone, mudstone, and shale make up the greater part of the formation.

BRECCIA

Basal breccia.—Breccia has been noted at the base of the Humboldt formation at a number of localities. These basal breccias are composed of angular fragments of the immediately underlying rock, which in many places is Carboniferous limestone. Some of the breccias have developed almost *in situ* by disintegration and spalling of exposed bedrock; others indicate considerable movement of material and resemble slope-wash breccia and fanglomerate.

[6] G. D. Louderback, "Period of Scarp Production in the Great Basin," *Univ. Calif. Pub. Dept. Geol.*, Vol. XV (1924), p. 36.

[7] Harrison Schmitt, "The Central Mining District, New Mexico," *Amer. Inst. Min. Met. Eng., Contr. No. 39* (1933), pp. 2 and 13.

Interbedded breccia.—At the north end of the East Humboldt Mountains on the east flank, N.E. $\frac{1}{4}$, Sec. 35, T. 37 N., R. 61 E., a limestone breccia is interbedded in the Humboldt formation. This breccia ranges from light to dark gray and is composed of extremely angular fragments of limestone, 1 inch to several feet in diameter, imbedded in a well-cemented matrix of limestone chips. The matrix makes up only 10–15 per cent of the whole rock. The breccia has been formed at the base of a steep slope, presumably a fault scarp, largely under the influence of gravity. In a single outcrop, 50 × 75 feet, the breccia is composed entirely of a uniform type of limestone, which suggests derivation from a single exposure. The lithologic differences between limestone beds in the pre-Tertiary rocks, from which the breccia was derived, are of such magnitude that a breccia of this uniform composition could come only from a relatively small outcrop. Largely for this reason, the breccia is thought to represent a slide and not a talus deposit, since the latter would be derived from a number of outcrops and therefore would contain blocks of several types of limestone.

Two distinct beds of breccia, separated by several hundred feet of coarse fanglomerate, have been observed. The lower breccia bed is the more extensive and crops out more or less continuously for 2 miles along the strike, parallel to the front of the range. The maximum thickness observed is about 100 feet, though the upper boundary is difficult to determine, for the breccia grades upward into fanglomerate. The lower breccia is underlain by silt, sandstone, and pebble-conglomerate beds.

The limestone breccia dips 25° eastward and lies a mile east of the bold scarp of the East Humboldt Mountains. Derivation from a newborn fault scarp in Miocene time is postulated for the following reasons: (1) The base of the present scarp exposes limestone similar to that composing the breccia. (2) The breccia appears to have come from a source to the west. (3) The abrupt lithologic change from silt, sandstone, and pebble-conglomerate to coarse limestone breccia indicates a quick change in deposition, such as would be caused by sudden uplift of a block by faulting. (4) The extreme coarseness of the overlying fanglomerate also indicates that it has been derived from a steep scarp. Deposits accumulated largely under

the influence of gravity at the foot of a scarp should be succeeded by slope wash and fan deposits. Two separate beds of breccia may indicate separate uplifts along the fault, but the upper breccia is of such limited extent that it may be a feature so local as to be due to some other and unknown cause.

Longwell[8] has recently described similar but more extensive breccias, which he regards as landslide breccias, on the flanks of the Virgin and Black mountains in the Boulder Reservoir region of Arizona and Nevada, and in another case from the Triassic beds of the Connecticut Valley. These breccias are also associated with fanglomerate (or fan breccia). Longwell has presented facts which strongly suggest that the breccias and associated fanglomerates were derived from an actively growing fault scarp.

Post-Humboldt movement along the fault at the east base of the East Humboldt Mountains indicates that the present scarp is younger than the Miocene scarp, from which the breccias were derived.

FANGLOMERATE

The thickest and most extensive fanglomerate is associated with the breccias just described. This fanglomerate is brown, gray, or nearly black, depending upon the type of rocks composing it. Angular fragments, a fraction of an inch up to 4 feet in length, of white, gray, buff, or black limestone, quartzite, and pebble conglomerate compose the fanglomerate (Fig. 2). These fragments are imbedded in a sparse, sandy to gravelly matrix. Some red, sandy lenses are interbedded in the mass. In places the fanglomerate is composed largely of quartzite fragments, in other places largely of limestone fragments; and all gradations between these two types of lithology seem to exist. It is well cemented and forms bluffs and prominent outcrops.

This fanglomerate immediately overlies the breccias described above and is transitional into them. It has been derived from the same fault scarp as the breccias, but at a later time, when the scarp was more eroded and dissected. The coarse detritus from the scarp

[8] C. R. Longwell, "Geology of the Boulder Reservoir Floor, Arizona-Nevada," *Bull. Geol. Soc. Amer.*, Vol. XLVII (1936), pp. 1420–29; "Sedimentation in Relation to Faulting," *ibid.*, Vol. XLVIII (1937), pp. 434–38.

was deposited in long, sloping fans, closely resembling those found at present along fault scarps.

On the west side of the Ruby Mountains, near the entrance to Secret Pass, a red fanglomerate, 200 feet thick, has been traced for a mile along the strike, subparallel to the mountain front. This fanglomerate may be related to the same uplift which produced the breccias and fanglomerate described above.

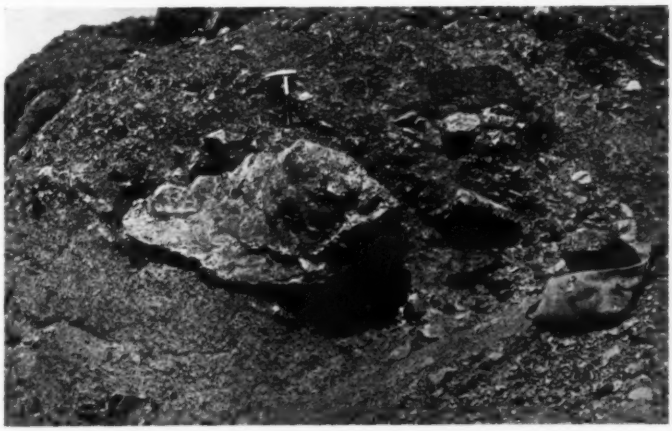

FIG. 2.—Fanglomerate interbedded in the Miocene Humboldt formation along the east flank of the East Humboldt Mountains. The fragments in the fanglomerate are limestone and quartzite. This fanglomerate has been derived from an actively growing fault scarp 2 miles to the west.

CONGLOMERATE

Basal conglomerate.—Basal conglomerate beds, 20–200 feet thick, have been mapped in several localities. At each locality these beds rest directly upon pre-Miocene rocks, chiefly Carboniferous limestone or quartzite. The conglomerate beds contain roundstones[9] up to 1½ feet in diameter.

Interbedded conglomerate.—Conglomerate was deposited near elevated areas which were supplying detritus to the Humboldt formation. Along the flanks of the Ruby–East Humboldt Range, con-

[9] Term suggested by F. A. Fernald (*Science*, Vol. LXX [new ser., 1924], p. 240) for pebbles, cobbles, and boulders, etc., in a conglomerate.

glomerate containing roundstones of the various rock types exposed in these mountains is abundant, indicating that an elevated mass occupied the present site of this range in Humboldt time.

Along Huntington Creek, south of Twin Bridges, conglomerate beds are abundant 1,400 feet above the base of the formation. The lowermost conglomerate in this locality is composed almost entirely of limestone with subordinate quantities of chert roundstones. Suc-

FIG. 3.—Conglomerate in the middle member of the Humboldt formation along Huntington Creek 2 miles south of Twin Bridges. This conglomerate contains pebbles and cobbles of limestone, quartzite, and granitic rocks.

cessive conglomerate beds higher in the section contain more roundstones of crystalline rocks, such as quartzite, gneiss, and granite. At 2,000 feet above the base a conglomerate bed contains roughly 50 per cent limestone and 50 per cent crystalline roundstones. At 2,300 feet above the base a conglomerate contains 75 per cent crystalline material; at 2,800 feet, 90 per cent crystalline material; and at 3,300 feet, approximately 100 per cent crystalline material. These relations indicate a gradual uncovering of the crystalline rocks which underlie the limestone within the mountain blocks.

The conglomerate in the Humboldt formation is a stream-laid deposit. Some of the conglomerate on the South Fork of the Humboldt River and on Huntington Creek contains well-rounded cobbles

up to 6 inches in diameter. These cobbles are at least 8–10 miles from a possible source, as far as known, and indicate transportation and deposition by a moderately powerful stream (Fig. 3).

SANDSTONE, MUDSTONE, SILTSTONE, AND SHALE[10]

Sandstone, mudstone, siltstone, and shale, with considerable intermixed fine pyroclastic material, grade one into the other and make

FIG. 4.—Conglomerate, sandstone, mudstone, and ash beds of the Humboldt formation along the north side of the South Fork of the Humboldt River, 2 miles above Twin Bridges, looking north.

FIG. 5.—Gently dipping conglomerate, sandstone, mudstone, and shale beds of the Humboldt formation along Huntington Creek south of Twin Bridges, looking northeast.

up the larger part of the Humboldt formation. These beds are white, brown, tan, and light green. They are composed of mineral fragments of the same type and origin as the roundstones in the conglomerate. Large quantities of fine pyroclastic material are intermixed with the detrital mineral fragments in many localities.

[10] These terms are used in the sense defined by the Committee on Sedimentation (*Rept. Comm. Sed., Nat. Res. Coun., 1936–37*, pp. 97–98).

The oil shale of the Humboldt formation is a thin-bedded, dark-colored, petroliferous shale exposed near the base of the formation in the Elko Range south of Elko. This shale contains considerable carbonaceous material and small fresh-water shells. Winchester[11] reports six separate groups of oil-shale beds in the vicinity of Elko; a single group of beds is seldom over a few feet or a few tens of feet thick. Dark-brown beds of lignite, a few inches thick, are interbedded with the oil shale.

FRESH-WATER LIMESTONE

Fresh-water limestone crops out near the base of the formation at a number of localities. The limestone is white to light brown, chalky to dense and finely crystalline, and ranges from thin beds a fraction of an inch thick to rather massive beds a few feet thick. Wherever observed, the limestone contains many shells of fresh-water gastropods and pelecypods. Along Huntington Creek near Twin Bridges the limestone contains a great number of irregular black, gray, and white nodules of chert, ranging from an inch to a foot in diameter.

Where exposures are good, the limestone is seen to rest directly on a basal conglomerate or breccia and to pass upward into limy shale, silt, sandstone, and ash. The oil-shale beds at Elko overlie the limestone. A thickness of 870 feet of limestone has been measured on Huntington Creek; this is the greatest thickness exposed.

DIATOMITE

Two groups of diatomite beds, each 7–10 feet thick, crop out near Carlin, 25 miles west of Elko. The diatomite is pure white, loose and friable, and moderately massive.

ASH AND TUFF

Ash and tuff beds are abundant about 1,000 feet above the base of the formation, and pyroclastic material is a common constituent of many beds higher in the formation. Many of the tuff beds are massive and give no evidence of being water-laid. They are composed of fragments and crystals of quartz, feldspar, biotite, glass, and angular fragments of rhyolite, and in places are lapilli tuff.[12] Most of the ash

[11] *Op. cit.*, pp. 98–100.

[12] C. K. Wentworth and Howel Williams, "The Classification and Terminology of the Pyroclastic Rocks," *Nat. Res. Coun. Bull. 89* (1932), p. 47.

beds are water laid and thin bedded. They are composed chiefly of fragments of volcanic glass and minor quantities of quartz and feldspar fragments.

RELATIVE PERCENTAGES OF LITHOLOGIC TYPES

An attempt has been made, in the accompanying table, to estimate the relative percentages, by volume, of the various types of sedimentary beds in the Humboldt formation. At best this is only a crude estimate, although for the localities studied it is based on detailed sections. As far as the whole formation is concerned, it may be considerably in error.

Type of Bed	Percentage of Formation by Volume
Limestone	5–10
Conglomerate	10–15
Sandstone, shale, mudstone, siltstone, etc.	60–75
Ash and tuff	5–10
Fanglomerate and breccia	2–3

STRATIGRAPHY AND THICKNESS

The Humboldt formation in the area studied possesses distinct lithologic characteristics which facilitate its division into three members as follows:

LOWER MEMBER

The lower member is composed of shale, oil shale, fresh-water limestone, sandstone, and conglomerate. Oil shale and limestone beds identify this member. In places the limestone and oil shale grade laterally into mudstone, sandstone, and conglomerate, and the member loses its distinctiveness. The lower member is 800–1,000 feet thick at places of maximum thicknesses but is missing or indeterminate at other places.

MIDDLE MEMBER

The middle member is characterized by rhyolitic tuff and ash. Tuff and ash beds are found throughout the formation, but they are particularly abundant in the middle member. A single outcrop of ash or tuff does not identify this member, but a thickness of a hundred feet or so of associated tuff and ash beds is distinctive within the writer's experience. Volcanic activity of an explosive nature

seems to have been at a peak at this time. The middle member has a maximum measured thickness of 1,300 feet.

UPPER MEMBER

The upper member consists of fine conglomerate, sandstone, mudstone, siltstone, and shale beds. Mudstone and shale are abundant near the top. The conglomerate is distinguished by a large proportion of quartzite and granitic pebbles, compared to the number composed of limestone. This member is identified by its great thicknesses of mudstone and shale and the relative paucity of conglomerate beds. The maximum measured thickness of the upper member is 3,600 feet, although it may be much thicker, for the top of the formation is not known.

Figure 6 is a series of columnar sections from various places in the area considered. The three members of the formation are indicated in these sections.

THICKNESS OF THE HUMBOLDT FORMATION

Near the city of Elko a well drilled for oil reach a depth of 3,200 feet in the Humboldt formation without reaching the base. The average dip in the vicinity of the well is 10°, and, assuming a straight hole and no structural complications, the thickness of beds drilled through is about 3,100 feet. Since the collar of the well is located an unknown distance below the top of the formation, the conclusion seems justified that the formation is more than 3,100 feet thick in the vicinity of Elko. The possibility that some of these beds do not belong to the Humboldt formation is not very strong, for the base of the formation is exposed at several places in the Elko Range near by and no trace of an older Tertiary formation is found.

By far the best-exposed and most continuous section of the Humboldt formation is along Huntington Creek south of Twin Bridges, where a section has been measured in detail by a pace and compass traverse. The data of this traverse are presented in column *A* of Figure 6. The base of the formation is exposed near Twin Bridges, but structural complications made an exact measurement from the base impossible. The section has been measured from a bed approximately 100 feet above the base to the eroded top of mudstone beds an unknown distance below the true top of the formation. A

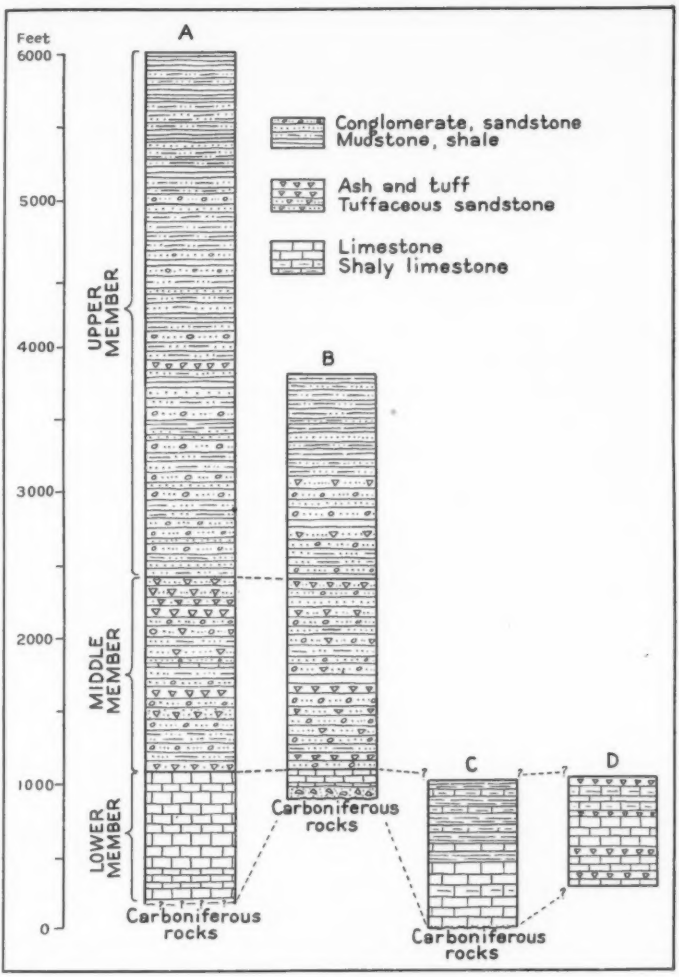

FIG. 6.—Columnar sections of the Miocene Humboldt formation. Section *A* measured along the east bank of Huntington Creek, starting immediately south of Twin Bridges and extending 4.6 miles to the south. Section *B* is a composite section measured on a series of cuesta faces in Lamoille Valley starting ¼ mile east of Twin Bridges and extending to Secret Pass, 25 miles to the northeast. Section *C* is from the Elko Range immediately south of Elko. Section *D* is from the east side of the Valley Mountains.

thickness of 5,800 feet has been measured in this way, and the formation is thicker by an unknown amount, although it is probably not everywhere so thick in the wide area of exposure in northeastern Nevada. This section along Huntington Creek should be considered the type section of the Humboldt formation, for it is the most completely exposed section of these beds known.

STRUCTURE

The Humboldt formation lies in a series of elongated basins separated by northward-trending, fault-block mountains. These basins have an average north-south length ranging from 25–100 miles and an east-west width in most places not over 25 miles.

UNCONFORMITY AT BASE

As far as known, the Miocene Humboldt formation rests upon a basement of pre-Tertiary rocks. No older Tertiary sedimentary rocks are known anywhere in the area studied. In several localities the Humboldt rests unconformably on Carboniferous rocks. This unconformity is particularly well exposed in the Elko Range near Elko, and it can be traced continuously 9 miles south to the gorge of the South Fork of the Humboldt River. Unconformable contacts between the Miocene and pre-Tertiary rocks have also been noted in the Burner Basin, 4 miles east of Elko; near Twin Bridges; near Thorpe Creek on the west flank of the Ruby Mountains; on Sheep Creek a bit farther south; and at the gorge of the Humboldt River west of Elko.

In several places beds of the middle member and even of the upper member overlap the lower beds and rest directly upon pre-Miocene rocks. A coarse conglomerate which rests directly on Carboniferous limestone at the mouth of Thorpe Creek may be taken as an example. This conglomerate contains a number of roundstones of gneiss, quartzite, and igneous rocks in addition to limestone. Along Huntington Creek roundstones of gneiss, quartzite, and igneous rocks do not appear lower than the middle member. Therefore, the base of the formation at the mouth of Thorpe Creek is within the middle member, at least, and considerable overlap of later over earlier beds is indicated.

FOLDS

Within the basins the Humboldt beds have gentle dips not over 15°, but near the foot of the mountains the structure is more complex with dips up to 50°. Near the mountains the basin deposits seem to be broken into separate blocks with diverse dips. The sections of Figure 7 show folds in the basin deposits; but these folds are largely diagrammatic and based upon reversals of dip, which may be related to either folding or faulting. In all probability the underlying basement has been fractured and faulted, and the overlying beds have yielded by faulting, folding, or warping. Near Twin Bridges on Huntington Creek a broad, open anticline has been mapped. This fold trends roughly northwest and the beds on the flanks dip from 20°–28°. Winchester[13] mentions warping and folding of the Humboldt formation in the Elko Range. However, it is clear that the Humboldt has not been folded by intense compressional forces; and it may well be that the folds, such as they are, represent normal faults in the underlying basement.

FAULTS

Many of the mountain ranges separating the areas of basin deposits are fault-block mountains, bounded on one or both sides by faults which separate the pre-Miocene rocks of the mountain blocks from the Miocene basin deposits. This relation is demonstrated along the west flank of the Ruby–East Humboldt Range, where streams have deeply dissected the mountain front and the forelying basin deposits. The Miocene beds dip toward the mountain block in many places; and ample evidence for faulting, such as truncation of structures and beds, triangular facets, actual exposures of the fault zone, and recent piedmont scarps, demonstrates that the basin deposits are separated from the rocks of the mountain block by a fault or faults. Where seen, the fault planes have basinward dips, and the faults are normal. Subsidiary normal faults of small displacements have also been observed in the basin deposits at several places.

RELATION TO YOUNGER ROCKS

In the Elko Range, pyroxene andesite and olivine-pyroxene basalt flows, breccia, and an associated tuff bed lie unconformably on the

[13] *Op. cit.*, pp. 94 and 96.

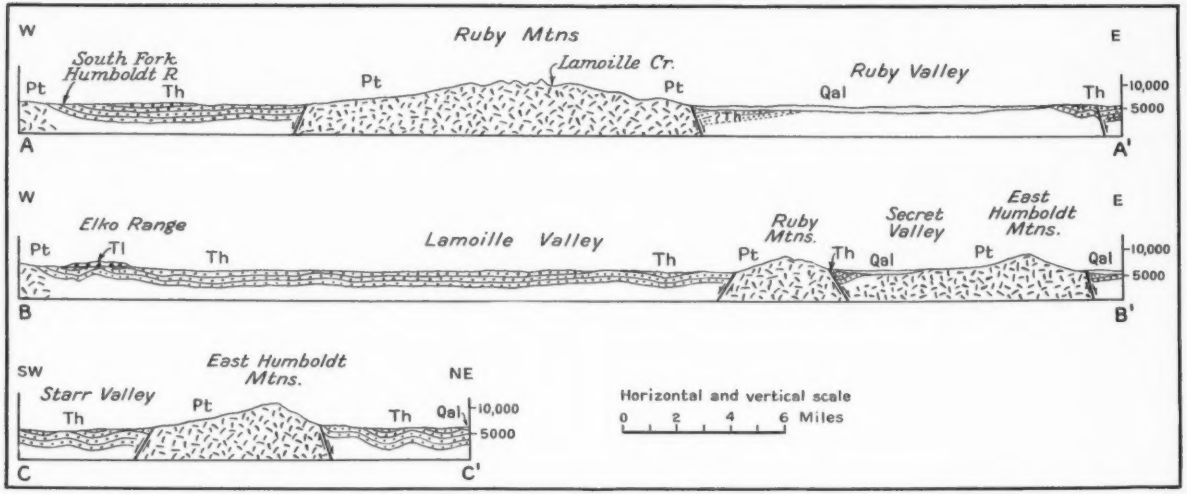

FIG. 7.—Structure sections illustrating the relations of the Miocene Humboldt formation (*Th*) to the older pre-Tertiary rocks (*Pt*) and to the younger Pliocene (?) lavas (*Tl*) and Quaternary alluvium (*Qal*). The locations of these sections are shown on the geological map, Fig. 9.

Miocene beds (Fig. 8). The suggestion is made that the rocks above the unconformity are of Pliocene age. As will be shown later, deposition of the Humboldt continued well into the late Miocene and possibly into the Pliocene. The time interval indicated by the post-Humboldt deformation and erosion prior to the extrusion of the lavas seems to be long enough to place them in the Pliocene. They

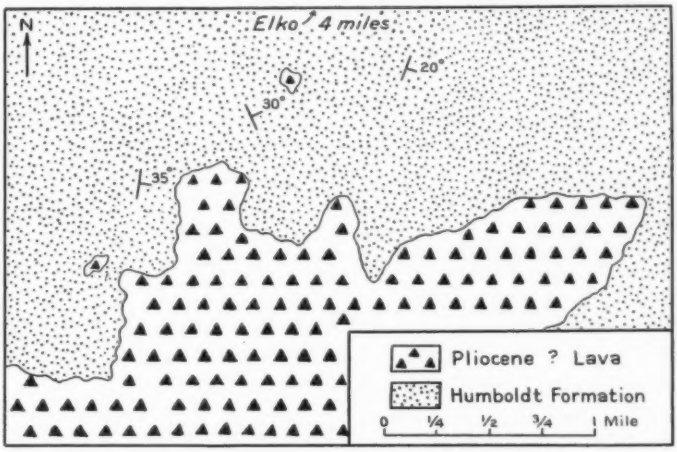

FIG. 8.—Pace and compass map made in the Elko Range 4 miles south of Elko; see Fig. 9 for exact location. This map shows the gently tilted Pliocene lavas overlying unconformably the deformed beds of the Miocene Humboldt formation.

appear too old to be Pleistocene. At the south tip of the East Humboldt Mountains, pyroxene andesite rests unconformably on Humboldt beds and overlaps Carboniferous limestone to the north and west. Basalt and andesite have also been noted lying unconformably on Humboldt beds north of the town of Deeth, on Maggie Creek north of Carlin, and in the low hills west of Huntington Creek.

Quaternary terrace and pediment gravels also rest unconformably on the eroded edges of the deformed Miocene beds.

RELATION OF THE HUMBOLDT FORMATION AND LAVAS

Rhyolite flows interbedded with the Humboldt beds have been mapped on the flanks of the East Humboldt Range. Petrographic study shows that these lavas are characterized by large (5 mm.)

resorbed phenocrysts of quartz and orthoclase set in a groundmass which has a latite-like texture. Seventy miles to the north of Elko, in the Jarbidge mining district near the Idaho-Nevada border, are at least 6,000 feet of rhyolite, thought by Schrader[14] to be Miocene (?) and Pliocene (?). Specimens of the Miocene (?) rhyolite collected at Jarbidge are so similar to the rhyolite interbedded in the Humboldt along the flanks of the East Humboldt Mountains as to suggest that they came from a common source. The similarity is even more striking in thin section. Schrader[15] reported lignitic shale and dark slaty sandstone seemingly interbedded with the Miocene (?) rhyolite near Jarbidge. It is highly probable that these sediments belong to the Humboldt formation. In addition, the large amount of rhyolitic ash and tuff in the middle member of the formation suggests contemporaneous volcanism somewhere in the vicinity. In short, the Miocene (?) rhyolite at Jarbidge appears to be contemporaneous with the Humboldt and, at least locally, is interbedded with it.

The relations of the Pliocene (?) lavas, rhyolite, andesite, and basalt, of northernmost Nevada and southern Idaho, to the Humboldt formation have not been determined. However, reconnaissance indicates that at Contact, 50 miles north of Wells, rhyolite lavas overlie unconformably basin deposits which are similar to, and probably belong to, the Humboldt. This rhyolite and other Pliocene (?) rhyolites of northernmost Nevada and southern Idaho are typically hypohyaline, tridymite rhyolites, strongly flow banded. They are much fresher than the Miocene rhyolites of Jarbidge and the Elko area and in no way resemble them.

Pyroxene andesite and olivine-pyroxene basalt flows and breccias overlie unconformably the Humboldt beds near Elko, as shown on the sketch map (Fig. 8). Similar relations between Humboldt beds and andesitic or basaltic lavas have been noted at the south tip of the East Humboldt Mountains (Fig. 9), at a point 5 miles north of Elko on the Mountain City road, on Maggie Creek north of Carlin,

[14] F. C. Schrader, "The Jarbidge Mining District, Nevada, with a Note on the Charleston District," *U.S. Geol. Surv. Bull. 741* (1923), pp. 17–21.

[15] *Ibid.*, p. 14.

a few miles north of Deeth, and west of Huntington Creek near Twin Bridges.

In this study andesite and basalt have never been found interbedded in the Humboldt formation but, where observed, overlie it unconformably. Coarse-grained rhyolitic lava has been observed interbedded with the formation, and fine-grained rhyolite has been observed overlying unconformably beds which may belong to the Humboldt. Although none of this evidence is compelling, it seems probable that much of the great mass of rhyolite north of the region studied is of Miocene age. This region was probably the volcanic center which supplied much of the pyroclastic material interbedded in the Humboldt formation.

AGE OF THE HUMBOLDT FORMATION

Vertebrate fragments have been collected or reported from the Humboldt formation at five localities:[16] (1) on the South Fork of the Humboldt River in several places along the cuesta on the north side of the road to Lee;[17] (2) on the North Fork of the Humboldt River near the McKnight Ranch, Merriam's[18] McKnight locality and King's[19] "Bone Valley" site; (3) near the "Triolite" mine 3 miles northeast of the town of Carlin, which is 25 miles west of Elko on U.S. Highway 40 (the place where fragments are most abundant is the southeast corner of Section 7, T. 33 N., R. 53 E.); (4) in Lamoille Valley along Rabbit Creek about 3 miles northeast of the Rossi Ranch, in the northwest quarter of Section 11, T. 34 N., R. 57 E.; (5) on Camp Creek, $\frac{1}{4}$–$\frac{1}{2}$ mile above the junction with Sussie Creek (this junction is 21 miles by road up Sussie Creek from U.S. Highway 40 [the Sussie Creek road turns off 2 miles east of Carlin], and the locality is in the southwest quarter of Section 36, T. 36 N., R. 53 E.).

The vertebrate fragments collected on the South Fork of the Humboldt River come chiefly from sandy-mudstone beds near the base of the middle member. The exact stratigraphic relations of

[16] Names of local residents who can be of assistance in finding fossil localities: Mr. R. A. Kinne, of the municipal water department, Elko, Nevada, and Mr. Gerald Trescarte, Lamoille, Nevada.

[17] These localities are all shown on Fig. 1 as V_1–V_5, respectively.

[18] *Op. cit.*, pp. 276–77.

[19] *Op. cit.*, Vol. I., p. 439.

King's "Bone Valley" site are unknown. The bones at the "Triolite" mine near Carlin are in sandy-mudstone beds 10 feet above the diatomite bed worked at the mine. The fossiliferous beds have been traced along the strike for about $\frac{3}{4}$ mile, and vertebrate fragments have been found throughout that distance. These beds are only a few hundred feet above the base of the formation, but there is good evidence of considerable overlap here, and they are probably in the middle member. The fossils on Rabbit Creek in Lamoille Valley are in sandstone and mudstone beds in the upper member. The Camp Creek locality is in sandy-mudstone beds interbedded with ash. The exact stratigraphic relations of these beds are not known, but their lithology suggests that they belong to the middle member of the Humboldt. By far the best locality seen, and the one most worthy of consideration as a possible collecting site, is the Camp Creek locality (V_5). Here whole bones are imbedded in the rock, and vertebrate remains have been found through a stratigraphic thickness of several hundred feet. All the material collected has been placed in the hands of Dr. Chester Stock, of the department of geology, California Institute of Technology, Pasadena, California.

The only vertebrate forms described from the Humboldt formation are those listed by Merriam[20] from the McKnight locality on the North Fork of the Humboldt River. These forms are:

Merychippus, sp., near *isonesus* (Cope)
Merycodus (?) sp.
Camelid, sp.
Carnivore fragments

According to Merriam, they indicate a stage in the latter half of the Miocene. Buwalda[21] has collected a vertebrate fauna from beds reported to be the same as King's Eocene. This fauna has been determined as Middle or Upper Miocene but has not been described, and the exact localities are not known to the writer.

Plant remains have been collected by various workers from the oil shale and associated beds in the vicinity of Elko near the base of the Humboldt, and the following species are listed by Knowlton.[22]

[20] *Op. cit.*, p. 276.

[21] Winchester, *op. cit.*, p. 91.

[22] F. H. Knowlton, "A Catalogue of the Mesozoic and Cenozoic Plants of North America," *U.S. Geol. Surv. Bull. 696* (1919), p. 796.

Comptonia partita (Lesquereux) Berry
Carpinus elkoana Lesquereux
Fagus feroniae Unger
Fagopsis longifolia (Lesquereux) Hollick
Ficus jynx Unger
Lycopodium prominens Lesquereux
Myrica brongniarti ? Ettingshausen
M. drymeja (Lesquereux) Knowlton
Planera ungeri Ettingshausen
Populus richardsoni ? Heer
Salix elongata O. Weber
S. media Heer
Sapotacites coriaceus (Lesquereux) Knowlton
Sequoia affinis Lesquereux
S. angustifolia Lesquereux
Thuja garmani Lesquereux
Myrica undulata (Heer) Schimper

Knowlton gives these forms as Miocene. The plants listed above have been collected from King's so-called "Eocene beds" near Elko. They definitely prove that the beds belong to the Miocene Humboldt formation and are not to be correlated with the Green River formation.

Mason[23] mentions two conifers from the Tertiary beds near Elko and gives the age of these deposits as Oligocene or Miocene.[24]

In this study some plant remains were collected from the oil-shale beds at the Catlin oil-shale plant near Elko, Sec. 22, T. 34 N., R. 55 E. Mr. William C. Darrah, of Harvard University, has studied these specimens and has kindly furnished the following note.

> The flora found in the oil shale at Elko, Nevada, is characterized by a small number of species which have very limited distributions. A half-dozen species are not known from any other locality. A few, such as *Sapotacites coriaceus* (Lesquereux) Knowlton and *Sequoia affinis* Lesquereux, which are of late Miocene age, are good "index species." A few poorly defined species, such as *Fagus feroniae* Unger, are useless for purposes of correlation. In view of the fact that the Lower and Middle Miocene floras of western North America are well known, the considerable number of endemic species in the Elko district further suggests a late Miocene age. The oil shale at Elko is most probably within the upper third of the Miocene.

[23] H. L. Mason, "Fossil Records of Some West American Conifers," *Carnegie Inst. Wash. Pub. 346* (1927), pp. 154–56.

[24] *Ibid.*, p. 140.

As this flora comes from the lower member of the Humboldt formation, it indicates that even the lower part of the formation is probably not older than late Miocene. The upper part of the Humboldt may possibly extend into the Lower Pliocene, although there is no direct evidence to support this statement.

In summary, all the evidence indicates that the Humboldt formation was laid down in the latter part of the Miocene, with deposition possibly extending into the Pliocene.

CONDITIONS OF DEPOSITION

MODE OF DEPOSITION AND PHYSIOGRAPHIC RELATIONS

The relatively fine-grained deposits at the base of the Humboldt formation indicate either that the mountain masses supplying detritus were not very high or that they were far distant from the Elko region in the early part of Humboldt time. Moderately large, permanent rivers flowed into a lake in which the limestone, oil shale, and related beds were deposited. The lack of deposits of soluble salts indicates that this body of water was drained, but the direction and nature of this drainage cannot be determined from the data at hand. In the area considered, no evidence of a single large through-flowing river, such as the existing through-flowing rivers of the Basin and Range province, like the Rio Grande or Humboldt, has been found.

The coarser deposits in the middle member of the formation reflect greater relief, presumably related to faulting, and perhaps drier climatic conditions in middle Humboldt time. The somewhat finer deposits, mudstone and shale, near the top of the formation probably indicate reduced relief near the end of the Humboldt period. The lack of lake beds near the top of the formation shows that the lake was filled up or dried up by that time. The conglomerate of the Humboldt formation is clearly a river deposit; and many of the sandstone, mudstone, and silt beds are river flood-plain deposits. As at least 75 per cent of the deposits are fluviatile, the use of the term "lake beds" to describe the whole formation is incorrect.

In northernmost Nevada and southern Idaho large volumes of lava were extruded, presumably, in what had theretofore been a part of the area receiving Miocene deposits. These lavas accumulated to a thickness of at least 6,000 feet and formed a broad table-land, or

dome. Near the edges of this table-land, or dome, the lava was interbedded with sedimentary deposits belonging to the Humboldt formation. This volcanic center probably supplied much of the pyroclastic material in the Humboldt beds 70 miles to the south in the Elko region. Part of this pyroclastic material was re-worked by streams and intermixed with other material; however, much of it was incorporated in the formation with little or no re-working by water.

The similarity of the Humboldt formation to other mid-Tertiary deposits of southern Idaho and western Nevada suggests that they were deposited under somewhat similar conditions and that possibly certain basins had a common watershed and even some continuity of area. However, the broader questions of the physiographic conditions of the mid-Tertiary in the Great Basin await the study of many other small areas like that considered here.

ENVIRONMENT

The Elko region has an arid to semiarid climate. Average annual rainfall is 6–10 inches in the basins and 15–18 inches in the mountains. The conditions during the deposition of the Humboldt formation must have been considerably different. The vertebrate fauna collected from the Humboldt indicates a climate somewhat more humid than the present—a climate which could support vegetation suitable for grazing animals, such as horses and camels. The plant remains point to a humid climate, in some cases with rainfall of 24–40 inches, as suggested by La Motte,[25] Berry,[26] Oliver,[27] Chaney,[28]

[25] R. S. La Motte, "The Upper Cedarville Flora of Northwestern Nevada and Adjacent California," *Carnegie Inst. Wash. Pub. 455* (1936), p. 89.

[26] E. W. Berry, "The Flora of the Esmeralda Formation in Western Nevada," *U.S. Nat. Mus. Proc.*, Vol. LXXII, Art. 23 (1927), p. 3; "A Revision of the Flora of the Latah Formation," *U.S. Geol. Surv. Prof. Paper 154H* (1929), p. 234; "Miocene Plants from Idaho," *U.S. Geol. Surv. Prof. Paper 185E* (1934), p. 101.

[27] Elizabeth Oliver, "A Miocene Flora from the Blue Mountains, Oregon," *Carnegie Inst. Wash. Pub. 455* (1936), p. 35.

[28] R. W. Chaney, "Flora of the Payette Formation," *Amer. Jour. Sci.*, 5th ser., Vol. IV (1922), p. 222; "The Mascall Flora, Its Distribution and Climatic Relations," *Carnegie Inst. Wash. Pub. 340* (1925), p. 43; "Geology and Paleontology of the Crooked River Basin with Special Reference to the Bridge Creek Flora," *Carnegie Inst. Wash. Pub. 346* (1927), p. 79.

and MacGinitie[29] for some of the mid-Tertiary western fossil floras, which contain forms similar to those in the Humboldt.

La Motte[30] has suggested that the Forty-nine Camp region of northwestern Nevada had both summer and winter rains. The Elko region 250 miles farther east probably also had summer and winter rains, as its geographical location is favorable to both.

As deposition of the Humboldt formation extended through a considerable part of the late Miocene and possibly into the early Pliocene, conditions probably changed during such a long time. The best evidence of humid climate is found near the base of the formation. Higher up, the vertebrate fauna seems to reflect less humid conditions, suggesting that the climate may have become progressively drier during the deposition of the formation. This seems to fit in well with the general picture obtained from other mid-Tertiary deposits of western United States as outlined by Clements and Chaney[31] and by Dorf.[32] A relatively humid climate in the Miocene and a drier climate in the Pliocene seems to be the general rule. The uplift of the fault-block mountains to the west, cutting off moisture from the Pacific Ocean, had not taken place to any great extent in early Humboldt time, though the less humid conditions of late Humboldt time may indicate that such uplifts were beginning to have effect.

ORIGIN OF THE MIOCENE BASINS OF DEPOSITION

The origin of the Tertiary basins of deposition in the Great Basin has long been a problem. The solution to this problem lies in the nature of the Tertiary deposits and in their relations to the pre-Tertiary rocks. The basins must have been either structural or erosional or, perhaps, in part both. If the basins were entirely erosional, some change in drainage must have occurred which caused them to become basins of sedimentation. The Miocene floras in the Great

[29] Harry D. MacGinitie, "The Trout Creek Flora of Southeastern Oregon," *Carnegie Inst. Wash. Pub. 416* (1933), p. 39.

[30] *Op. cit.*, p. 89.

[31] F. E. Clements and R. W. Chaney, "Environment and Life in the Great Plains," *Carnegie Inst. Wash. Suppl. Pub. 24* (1936), pp. 1–54.

[32] Erling Dorf, "Pliocene Floras of California," *Carnegie Inst. Wash. Pub. 412* (1930), pp. 34–66.

Basin indicate annual rainfalls from 24 to 40 inches,[33] which is certainly sufficient to maintain an integrated drainage unless some diastrophic change occurred, causing a disintegration of the drainage. The basins of deposition may have been developed in part by erosion, but diastrophism seems to have been the immediate factor causing them to become basins of sedimentation.

If the basins were of tectonic origin, they may have originated by warping or faulting. The lower member of the Humboldt formation is composed largely of fine-grained material. These fine-grained deposits indicate that the basins came into existence slowly and without sudden upheavals of any large magnitude. Small-scale faulting or gentle warping could account for the initiation of the basins. Spurr,[34] Louderback,[35] and Davis[36] have suggested that these basins originated through warping, but they have presented no evidence in support of this view. At a later date, at least in the Ruby–East Humboldt region, faulting has definitely played an important part in outlining the basins. Faulting during the deposition of the Humboldt formation is indicated by the interbedded breccia and fanglomerate at the north end of the East Humboldt Mountains near Wells. These coarse deposits have been described in the section of the paper treating lithology, and the reasons for considering that they were deposited at the foot of a fault scarp are given there.

The exact outline of the original area covered by the Humboldt formation in northeastern Nevada cannot be given as yet. It was a large area extending at least 150–200 miles from north to south and a corresponding distance east and west. The outcrops of the formation were once more continuous than at present, for late Cenozoic faulting has created basins separated by mountains. The area receiving deposits was not a single and simple basin. It may have been a series of connected intermontane basins or an irregular depression

[33] La Motte, Berry, Oliver, Chaney, and MacGinitie, in the works previously cited.

[34] J. E. Spurr, "Origin and Structure of the Basin Ranges," *Bull. Geol. Soc. Amer.*, Vol. XII (1901), p. 266.

[35] G. D. Louderback, "Basin Range Structure of the Humboldt Region," *Bull. Geol. Soc. Amer.*, Vol. XV (1904), p. 337.

[36] W. M. Davis, "The Peacock Range, Arizona," *Bull. Geol. Soc. Amer.*, Vol. XLI (1930), p. 312.

with island-like highlands within its borders. One of these highlands occupied the present site of the Ruby–East Humboldt Range, and from it detritus was poured into the basins by local streams.

In the main, the Elko area was made favorable for deposition by an extensive and gradual differential warping or small-scale faulting,

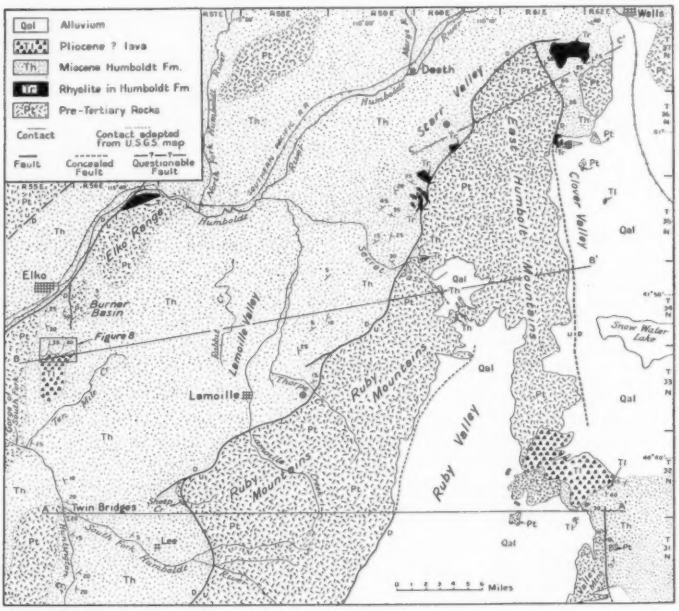

FIG. 9.—Geological map of the Humboldt formation in the vicinity of the Ruby–East Humboldt Range. The location of this map is shown in Fig. 1.

which, combined with erosion, produced a series of depressions separated or broken by low ridges. After deposition had continued for some time, the depressions were blocked out by faulting. The present pattern of mountain and basin blocks was outlined by faulting during Humboldt time and has been perpetuated by periods of recurrent faulting, continuing to the present.

SUMMARY

The Humboldt formation is composed chiefly of conglomerate, sandstone, mudstone, and shale. Considerable rhyolitic ash and tuff,

and smaller amounts of fresh-water limestone, oil shale, diatomite, breccia, fanglomerate, and thin interbedded rhyolite flows compose the remainder of the formation. The sedimentary deposits are of fluviatile and lacustrine origin.

Three members can be distinguished. A lower member, 800–1,000 feet thick, is identified by limestone and oil shale. A middle member, 1,300 feet thick, is identified by an abundance of rhyolitic ash and tuff beds. An upper member, 3,600 feet thick, is identified by thick sections of sandstone, mudstone, and shale with few conglomerate beds. The Humboldt formation has a measured thickness of 5,800 feet, and it may be thicker.

Vertebrate and plant remains indicate that the formation was deposited in the latter part of the Miocene, with deposition extending possibly into the Pliocene.

As far as known, the basin deposits rest on a basement of pre-Tertiary rocks. This contact, where exposed, is a distinct unconformity. At present, the Humboldt beds lie in a series of basins separated by fault-block mountain ranges of older rocks. At the edges of many of these basins the Miocene beds are separated from the older rocks of the mountains by normal faults. The structure of the Miocene beds is simple in the center of the basins and complex at the edges.

Data are presented which suggest that Miocene (?) lavas to the north of the general area of basin deposits are interbedded with the Humboldt beds near Jarbidge.

The beds of the Humboldt formation were deposited in a series of connected intermontane basins or an irregular depression, which, in early Humboldt time, was covered in part by a lake or lakes; later the lakes dried up or were filled up. The greater part of the formation was deposited along river courses and on flood plains by moderately large, permanent streams. The initially low relief was increased in middle Humboldt time, presumably by faulting, and somewhat reduced by erosion toward the end of the Humboldt period. Contemporaneous volcanism, 70 miles north of the Elko region, built a broad lava table-land, or dome, and supplied large quantities of fine pyroclastic material to the Humboldt formation.

The flora and vertebrate fauna from the Humboldt indicate conditions considerably more humid in the later Miocene than at present.

The nature of the Humboldt beds and their relations to the pre-Miocene rocks show that, although deposition of the formation may have started in consequence of widespread warping or small-scale faulting, some of the mountain and basin blocks were outlined by faulting at a later time during the deposition of the Humboldt formation. This fault pattern has been perpetuated by post-Humboldt movements extending to the present.

ACKNOWLEDGMENTS.—Professors Kirk Bryan and Marland Billings, of Harvard University, have made many excellent suggestions and criticisms in the field and in the preparation of this paper. Mr. William C. Darrah, of Harvard, has kindly identified the paleobotanical material collected in the Elko region. Dr. George H. Anderson, who is to make a study of the internal rocks and structures of the Ruby–East Humboldt Range, kindly permitted the writer to make this study in an area to which he had prior claim. Local residents, too numerous to mention, have extended many kindnesses during the course of the field work.

METAMORPHISM OF A GRANITIC DIKE AT FRANKLIN, NEW JERSEY[1]

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Washington, D.C.

ABSTRACT

A body of rock occurring near the Franklin Furnace ore body has been variously interpreted by writers on the local geology. This paper is a further study, leading to the view that the rock, hitherto considered of sedimentary origin, is an altered pegmatite dike.

INTRODUCTION

THE "ARKOSIC QUARTZITE"

The dikelike mass herein described occurs in the limestone quarry immediately to the south of the Buckwheat Mine at Franklin, New Jersey. It is entirely distinct from the minette dikes that cut the ore body in the mine itself and from the pegmatite that is indicated (on the Franklin Furnace Special Map, *U.S. Geol. Surv. Folio 161*) a few hundred feet to the east. The Franklin limestone has been quarried all around it, leaving the siliceous rock, with its silicified contact zone, well exposed in the middle of the quarry (which has now been abandoned).

The occurrence is of no great size or of any special economic significance, but it deserves attention for several reasons. It is conspicuous locally and has been studied by several geologists, cited below, and various interpretations have been placed on it. With the new information available, the conflicting views and anomalous characters of earlier accounts can be cleared up. Further, there is a special interest attached to any lithologic unit of an ore deposit as famous as Franklin Furnace; each year many students of geology visit the locality, and any information concerning the area should be on record.

The rock is not mentioned or mapped in the Franklin Furnace Folio,[2] although it was discussed in considerable detail in the

[1] Published by permission of the Director, U.S. Geological Survey.

[2] A. C. Spencer, H. B. Kümmel, J. E. Wolff, R. D. Salisbury, and C. Palache, *U.S. Geol. Surv. Folio 161* (1908).

Eighteenth Annual Report of the U.S. Geological Survey[3] a few years before. Its omission from the *Folio* was due to its comparatively small size and to the uncertainty existing at the time as to its character.[4]

Wolff and Brooks refer it to the Hardystonville quartzite of Cambrian age; but Spencer tentatively correlated it with the quartzitic members of the pre-Cambrian Franklin limestone, which are described at length in the *Folio*.

Under the heading "Hardystoneville Quartzite" Wolff and Brooks state:

> The quartzite also occurs in several small isolated patches lying on top of the white limestone and without the usual succeeding blue limestone (Walkill) . . . . at the new quarry at Franklin Furnace . . . . we found distinct pebbles of typical

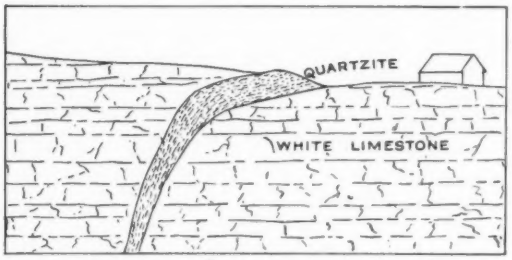

FIG. 1

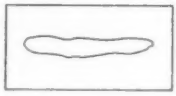

FIG. 2

FIG. 1.—Vertical quarry face showing band of quartzite in white limestone. (From Wolff and Brooks.)

FIG. 2.—Pebbles of white limestone 10×3 inches, occurring in quartzite band. (From Wolff and Brooks.)

> white limestone embedded in the quartzite. . . . . There can be no doubt but that these minerals in the quartzite are clastic . . . . a small patch of quartzite (arkose) lies on top of the white limestone. It is 10 or 15 feet thick, strikes about east and west, and dips 10° north. It entered the white limestone, curving gradually downward and contracting until it was about 3 feet thick at the bottom. The top and bottom contacts show no sign of faulting. It has entirely been formed in place. The rock is a pyritiferous quartzite, composed of clastic quartz, feldspar, light yellow muscovite, and a cement, partly fine-grained silica, partly

[3] Part II (1897), "The Age of the Franklin White Limestone of Sussex County, New Jersey," by J. E. Wolff and A. H. Brooks.

[4] Spencer, oral communication.

calcareous. It has been quarried out in large blocks, exposing the rock in ideal freshness. The important feature seen in these blocks is that large pebbles or boulders of typical white limestone are included in the quartzite. The rock composing the pebbles has scales of graphite and yellow mica, and the broad cleavage faces of the calcite masses show the dull spots (luster mottling) due to small poikilitic grains of calcite with different orientation, which is characteristic of the white limestone. Pieces from the main ledge of white limestone have the same minerals and the same structure so that their nature as pebbles and their source are beyond question. The largest observed had the shape and size shown in the cut; others are rounded. The rock also contains round masses of purple fluorite associated with quartz and calcite, which are probably concretionary but have no resemblance to these pebbles. There are occasionally black slaty stratification bands in the rock, which conform to the contacts, so that the stratification curves with the band of rock. . . . . It is plain the quartzite (arkose) contains the debris of the white limestone, and was laid down on its eroded surface, which was necesssarily creviced and irregular, and the peculiar form of the deposit we think can only be explained as due to the washing of sand into a large cavity.[5]

Further, these authors state:

Isolated particles of the quartzite are found within the white limestone area, which were originally deposited on the eroded and creviced surface of the white limestone filling in the irregularities, and sometimes causing the peculiar intermingling which has been described. The fortunate preservation of one of these crevices filled with quartzite containing undoubted pebbles of the white limestone, as well as arkose material, leaves no doubt as to their origin.[6]

Although the occurrence is not referred to in the Franklin Furnace Folio, Spencer makes the following statements concerning siliceous members in the Franklin limestone, with which he tentatively correlated the quartzitic rock: "Some of it is rather siliceous, and in a few places thin beds of sandstone have been noted. . . . . Associated quartzites . . . . certain beds of siliceous rocks which occur with the white limestone at three localities."[7] The first of these is at the old Andover iron mine, some 11 miles to the southwest of Franklin Furnace, and consists of siliceous breccia and indurated carbonaceous shale, in strata having a maximum thickness of 80–100 feet and that extend for some 1,300 feet. They contain irregular masses of hematite and magnetite and are in conformable contact with

[5] *Op. cit.*, pp. 442 and 454.

[6] *Ibid.*, p. 457.

[7] *U.S. Geol. Surv. Folio 161*, pp. 2 and 4.

gneisses; the limestone contact is not exposed, although several narrow bands are present near by. The other two occurrences of quartzitic rock are in the main belt of white limestone: one at the Simpson hematite mine, 4 miles to the northeast of Franklin Furnace, and the other, a mile farther north. At both of these places the rock is a glassy quartzitic conglomerate, which is dull red in color from the presence of considerable hematite, and apparently unlike the quartzitic rock under discussion.

There are serious difficulties involved in Wolff and Brooks's explanation. A considerable unconformity, with development of karst topography, is demanded; and definite evidence for this is lacking. Also, the several features they interpret as phenomena of sedimentation are equally well explained by igneous activity. If their explanation is correct, one should expect many of these quartzitic masses, but, as far as the writer is aware, this is the only occurrence of the kind in the Franklin limestone. Moreover, the definitely dikelike shape of the mass (as shown in their sketch, Fig. 1) casts a doubt on their conclusion. The authors themselves were aware of this difficulty, for they say: "It is difficult to understand why the stratification curves downward instead of lying horizontally across the original cavity. We simply note that such is the fact."[8]

Spencer, who worked in the area subsequently, realized the difficulties Wolff and Brooks's explanation presented, but, with the larger problems of the ores to deal with, detailed chemical and petrographic investigation of this minor problem was not undertaken. The rock was undoubtedly quartzitic (arkosic) in aspect, and, not being in a position to question the sedimentary characters postulated by Wolff and Brooks, Spencer referred it to pre-Cambrian sedimentation in the Franklin.

FIELD OBSERVATIONS

The two photographs indicate the size, structure, and relations of the occurrence. Figure 3 is a view of the quarry from the west. The dark area behind the tree is the quartzitic mass, with adjacent limestone not removed by quarrying. To the left and right some 200 feet back is seen the eastern face of the quarry, the Franklin limestone

[8] Wolff and Brooks, *op. cit.*, p. 455.

showing light gray. This quarry face (at the right, near the house) shows the trace of a fault, dipping northerly about 25°. Figure 4

FIG. 3.—View of quarry from the west, showing limestone block with dark quartzite in center of quarry (behind tree). Note fault in limestone starting below house at right.

shows a close-up view of the quartzitic mass from the north, taken from the quarry floor. The dark mass with irregular fracture just

left of the center is the quartzitic rock; to the right and left is Franklin limestone, showing lighter gray in the picture.

FIG. 4.—View of quartzite, close-up, looking south from quarry floor. The limestone is to the right and left of the dikelike mass.

The quartzitic rock as a whole is gray and ranges in texture from moderately granitoid (the grains a millimeter or less in diameter) to

dull, stony, aphanitic (the "black slaty stratification bands" of Wolff and Brooks). A third facies is a mixture of these two with much calcareous material (the "conglomerate" of these writers). The rock is fresh and unaltered by weathering. Pyrite and fluorite are commonly visible. Emanating from the quartzitic body are thin but persistent quartz veins carrying pyrite; also there are thin narrow veins of crystalline calcite which pass out into the limestone. The contact of the granitoid rock with the limestone is usually sharp, but in places there is marked brecciation of the contact zone. On the dump is marble-carrying chondrodite and other contact silicates.

Through the courtesy of Mr. Allen W. Pinger, geologist for the New Jersey Zinc Company, the following very satisfactory account of the geological relations can be given.

. . . . Drill holes were drilled a number of years ago, along an east-west line about 1,500 feet north of the quarry, and east of the Franklin mine. In several of these holes "quartzitic" material was found, associated with fluorite, and traces of blende, pyrite, and quartz, of character very similar to that found in the quarry.

There is a pronounced east-west slip, or fault, traceable for a distance of about 400 feet across the quarry. This slip dips to the north at an observed angle of about 25°. Displacement along the fault is doubtful. All of the occurrences of "quartzite," "arkose," "breccia," and dark aphanitic material were found to be directly associated with this slip; the greater part of such material was in the hanging wall, and a lesser amount in the foot-wall side. The "quartzitic" or "arkosic" material was more uniform in distribution than the darker aphanitic material. The latter is very irregular in shape and has distinctly intrusive-border characteristics.

The coarse white calcite areas, the white limestone "pebbles" of earlier descriptions, appear to us to be clearly secondary calcite filling irregular cavities and gash veinlets. The quartz, fluorite, and sulphides are strongly localized along the contacts of the "quartzitic" and aphanitic material, and locally in cross-cutting veinlets.

Parallel to the slip, and extending irregularly from 1 to perhaps 8 or 10 feet farther into the white limestone than the "quartzitic" material, is a band of gray dolomitized limestone, locally siliceous, with sharp boundaries against the normal white limestone, and extremely vague boundaries against the "quartzitic" material. The banding of the white limestone, marked by linear arrangement of accessory minerals, strikes NNE and dips regularly to the east. From many observations during our detailed study of the area, we are confident that this banding represents original sedimentary structure in the white limestone. Thus it is seen that the localization of the "quartzitic" material is not con-

formable to the structure of the white limestone and hence is not of contemporaneous sedimentary age with the white limestone. Elsewhere in the district we have found quartzitic bands made up of well-rounded quartz grains; these bands are conformable with the banding in the white limestone.

The occurrence of the "quartzitic" material, with associated fluorite and sulphides, in the drill holes, is found at about the same depth in each hole, and the depth correlates well with the observed dip of the slip in the quarry, with which the material appears to be associated.

At the north end of the Franklin mine, we have some evidence of an old karst topography below, or rather at, the pre-Cambrian erosion surface of the white limestone, with argillaceous and quartzitic material occurring locally in the old sink holes and crevices in the white limestone a short distance below the base of the Hardiston quartzite. This explanation, however, does not agree with conditions observed at the quarry locally, for a reconstruction on a section drawn normal to the Hardiston contact and through the quarry indicates the present position of the material in the quarry to be at least 1,200, and probably 1,500, feet below the erosion surface on which the Hardiston formation was lain down. We have no evidence of faulting which might modify this structure. The depth seems to us to rule out the Hardiston quartzite explanation.[9]

PETROGRAPHIC DESCRIPTION

The three types above mentioned—the granitoid, the stony, and the contact—will now be described in detail.

The coarse granitoid type is a light-gray rock, composed of rounded and irregular-shaped grains of quartz, microcline, and microperthite, in a groundmass of similarly shaped and sized grains of carbonate and fine-grained turbid material. This turbid material, sharply distinguished from the clear homogeneous grains of the minerals enumerated, consists of small grains of the foregoing minerals, with some sodic feldspar, and minor quantities of fluorite and chlorite. There are also present subhedral zircon, euhedral pyrite crystals in sharp pyritohedrons, and some pale-yellow sphalerite. Some of the microcline grains contain round inclusions of quartz, and some of the quartz grains contain similar inclusions of microcline. The zircon crystals are found as inclusions both in the quartz grains and in the groundmass, but the pyrite crystals and sphalerite are restricted to the groundmass. Plate I, *A*, gives the appearance of the rock under ordinary light and clearly indicates the isolation of the quartz and feldspar grains (one of them on the edge to the right)

[9] Written communication.

from the groundmass or matrix. The general aspect is indeed not unlike that of an arkose, with a calcareous-shaly cement. Under crossed nicols, however (Pl. I, *B*), it is seen that the greater part of the matrix is optically continuous with the quartz grains it surrounds. Between the grains of quartz, the intervening turbid matrix divides sharply, one half being quartz optically continuous with one grain, the other half having a similar relation to the other. The microcline grains show a similar phenomenon though to a less marked degree. The turbidity of the zone surrounding the quartz grains is due to immense numbers of liquid inclusions, many of which contain moving bubbles. In the zone surrounding the feldspars, the inclusions are too minute to be identified.

The stony type is of a darker gray than the coarse; it has a glittering appearance due to innumerable perfectly euhedral pyrite crystals, just large enough to visibly reflect light, that are distributed throughout the dull stony rock. Its uniform appearance is broken by threadlike veins of white siliceous material which cross it in various directions. Microscopically, the rock is seen to consist of an interlocking uniform aggregate of grains of quartz and albite-oligoclase. Scattered throughout this aggregate, in addition to the pyrite, are flakes of sericite, grains of rutile and titanite, and small irregular patches of magnesian calcite. A little sphalerite is found here and there. Plate I, *C*, shows the general uniform character of the stony type with the disseminated pyrite crystals.

The rock also contains well-marked veinlets which appear to consist solely of densely crowded crystals of pyrite, such as shown in Plate I, *D*. Here the pyritic vein appears to have acted as a barrier to the later vein of quartz with small rutile needles, shown in the center of the picture. The quartz vein appears to have been dammed up at the left of the pyrite barrier; only a little quartz got through at the right, and the rutile needles were filtered out.

The contact, or breccia, type consists of a mixture, in varying proportions, of limestone and the stony and granitoid types, together with fairly large flakes of phlogopite, pyrite, sphalerite, and purple fluorite. There are also prominent clear-white carbonate areas (the "pebbles" of Wolff and Brooks). The coarser granitic rock and the other materials of the breccia grade into one another, so that in

specimens it is difficult to tell where one ends and the other begins. The fine-grained darker rock, however, appears to be in rather sharply defined homogeneous blocks. Microscopically, the coarse- and fine-grained types may be readily recognized. The isolated microcline and quartz grains of the coarse-grained type are abundant and are surrounded and corroded by the fine-grained aggregate characteristic of the fine-grained stony type. The large microcline and quartz grains are shattered and crossed by veins of calcite containing feldspathic material. Likewise the mica grains show mechanical effects, being broken and bent along the cleavages, with frequent displacement of the pieces.

Plate II, *A*, shows shattered mica, and Plate II, *B*, a feldspar crystal, broken and invaded by the fine-grained felsic matrix material, which appears black in the photomicrograph. The bright clear area in the center of the feldspar is an included quartz grain, mentioned above as occurring in the feldspars.

Analyses of the coarse-grained and fine-grained types of rock gave the results shown in the accompanying tables (Tables 1 and 2).

A comparison of the analysis of the fine-grained stony phase with the coarser one shows a decrease in SiO_2 and K_2O, with an increase in Al_2O_3, Fe, and S. Mineralogically, the coarser-grained facies contain more quartz and microcline whereas the finer-grained has very much more albite and more pyrite.

DISCUSSION AND CONCLUSIONS

All who have examined the coarser-grained type of the quartzitic mass agree that the quartz and feldspar grains are entirely similar in character to those of the nearby granitic intrusives. A thin section of granite found in the same locality (on the dump) shows precisely the same inclusions of quartz in microcline and of microcline in quartz. There is also the absence of ferromagnesian accessories, such as pyroxenes, amphiboles, or dark micas. Were it not for the peculiar matrix of the coarse-grained type with the isolated distribution of the quartz and feldspars, one would readily admit that it is an aplitic dike. The theory of a sedimentary origin has rested on this matrix, the "black slaty" rock and the "conglomerate of white lime-

stone"; but, if these can be shown to be of igneous origin, the argument for its sedimentary character falls to the ground.

The analysis of the fine-grained "black slaty rock" indicates some 30 per cent of albite. As a rule, potash greatly exceeds soda in slaty

TABLE 1

COMPARISON OF CHEMICAL COMPOSITION OF COARSE (GRANITOID) AND FINE (STONY) TYPES

	Coarse-grained (%)	Fine-grained (%)		Coarse-grained (%)	Fine-grained (%)
SiO_2	82.00	77.44	CO_2	3.25	0.51
Al_2O_3	5.19	8.33	P_2O_5	.....	Tr.
Fe_2O_3	0.13	1.22	F	0.47	.....
FeO	.....	Tr.	S	0.43	2.05
MgO	2.05	1.50	Fe (as pyrite)	0.40	1.36
CaO	2.19	0.52	Zn (as sphalerite)	.....	Tr.
Na_2O	0.28	3.84		100.80	99.62
K_2O	3.56	1.58			
H_2O-	0.05	1.07	(O correction for F)	0.20	
H_2O+	0.64			100.60	
TiO_2	0.16	0.20			

TABLE 2

MINERALOGICAL COMPOSITION COMPUTED FROM ANALYSES

	Coarse-grained (%)	Fine-grained (%)		Coarse-grained (%)	Fine-grained (%)
Quartz	66.5	46.9	Pyrite	1.0	3.4
Microcline	18.6	8.9	Rutile (with sphene)	0.2	0.2
Albite	2.6	32.5	Chlorite	0.3	5.1
Muscovite	4.1	0.9	Sphalerite	.....	Tr.
Magnesian calcite	6.7	1.2			
Fluorite	1.1	.....		101.1	99.1

rocks. Besides, the thin section does not show the character of slate, or argillite, as there is no slaty cleavage or banding, or development of chiastolite, garnet, or the other minerals of this nature commonly found in metamorphosed argillaceous rocks. Replacement of potassic feldspar by sodic feldspar is the rule in metamorphism of igneous rocks; and corrosion and embayments in quartz grains are typical of effusive rocks such as dacites and similar siliceous types. Microscopic

examination shows the partial replacement of microcline and quartz by a fine-grained albitic aggregate and indicates clearly that the rock is not a slaty sediment. It seems probable, therefore, that the fine-grained stony rock was derived from the coarse-grained potassic type.

A polished slab of the "breccia" shows the limestone fragments to be angular, with little or no suggestion of rounding. Under conditions of sedimentation, one would expect a soft rock like a limestone to show some rounding. Furthermore, the particles of limestone range in size from a few centimeters down to microscopic dimensions, and there is no indication of size sorting. In a conglomerate, both rounding and some degree of sorting would be expected; the absence of such features further weakens the sedimentary interpretation of the rock. If the occurrence is entirely of igneous, nonsedimentary character, several questions present themselves. (1) Why in such a small body should there be two such sharply differentiated rock types as the coarse and fine? (2) What is the explanation of the peculiar matrix in the coarse-grained facies? (3) Why should we find this occurrence just where it is, i.e., what is its relation to surrounding rock bodies; and why should it, as far as known, be the only occurrence of the kind in this district?

The first question may be answered in general terms by the reasonable assumption that the agent of transformation of the coarse to the fine type was limited in amount. There was enough to transform so much of the coarse phase, and no more.

The second question, as to the matrix in the coarse type: Quartz grains with secondary shells of growth are well known in limestones, where circulating waters deposit silica on quartz grains. This explanation of the zone surrounding the quartz, however, cannot be applied here. One would have to assume some interstitial material, now completely removed, which the growing quartz grains replaced. There is no evidence of any such material. One alternative explanation is that we have here not a case of secondary growth but one of dissolution or corrosion. Digestion of the quartz grains had proceeded so far that the outer portion of each grain was thoroughly soaked and permeated by the invading solution. Had nothing inter-

fered, this soaked zone would have passed completely into solution, and in its place would have been deposited the fine-grained quartz-albite rock, with the excess silica forming the veins already referred to. But, for some reason, the digesting solution ceased to be supplied, and the outer zone of the quartz grains took on the aspect now seen, the outer zone with its liquid inclusions remaining to indicate the extent to which the individual grains were attacked.

Another possible alternative explanation of the turbid zone separating the clear quartz and feldspar grains is that it is composed entirely of material introduced between the clear grains, which have not been corroded at all, their shape resulting from shattering of the massive granitic dike. According to this view, the dike was locally broken up with the fractures following more or less closely the surface of the constituent grains, and, in the openings thus produced, the fine-grained quartz-albite aggregate crystallized. In the presence of the solid quartz grains already present, the liquid would tend to deposit quartz first; and its orientation would be governed by the quartz grains around which it was deposited.

Lastly, as to the relation to surrounding rock bodies: The quartzitic mass is considered to have originally been one of the many granite dikes found in the vicinity, cutting the Franklin limestone, and to have undergone a degree of metamorphism through a transforming solution of limited quantity. A few hundred yards away great dikes of highly alkaline minette of post-Ordovician age intrude the Franklin limestone. It is known that the minette magma generated large quantities of highly sodic differentiate, which was capable of leaving the minette in which it originated and passing out some distance. It is suggested that such a sodic differentiate met and reacted with the quartz-microcline dike. It is then the fortuitous nearness of the pre-Cambrian granitic dike and the post-Ordovician minette that has effected this type of alteration, found nowhere else among the dike rocks of the area.

This interpretation is confirmed by examination of certain inclusions of granitic dike material found within the minette itself. One of these, obtained through the kindness of Mr. Pinger, is labeled: "Pegmatite inclusion in dike (minette) south end of mine, 400-foot

level. Apparently similar to pegmatite which locally forms walls of dike." The two photomicrographs (Pl. II, *C* and *D*) of this specimen show a striking resemblance to the features described in the so-called "quartzite." Evidently, the minette magma still retained,

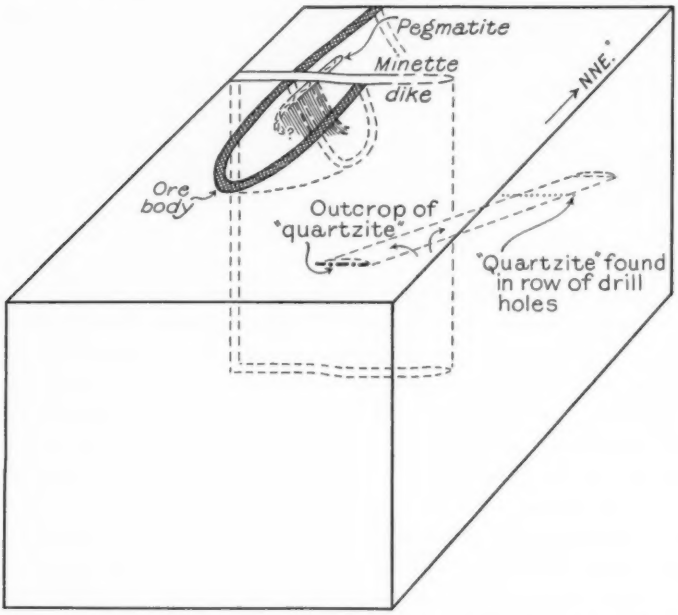

FIG. 5.—Diagram of inferred relations of the "quartzite" to the minette dike at Franklin Furnace. The intersection of the minette and the "quartzite" has not been observed underground, if the minette extends that far to the east. It is likely that the sodium-bearing solutions came from some deeper source in the minette (indicated by the two arrows). The pegmatite inclusions illustrated in Plate II, *C* and *D*, came from the small pegmatite dike intersecting the minette.

even at this comparatively shallow depth, sufficient albitic liquid to effect the moderate amount of albitization illustrated; and the result is a rock with features very similar to those shown in Plate I, *B*.

The intrusion of the minette into the complex system of diverse rocks, including the Franklin limestone, the ore body, the "quartz-

ite," and others, must have been the occasion of strains and dislocations in the intruded rocks. The large mass of limestone would yield easily under deformation, taking up the stress by gliding in individual crystals and general recrystallization. Such accommodation would not be possible in a quartz-feldspar rock such as the dike; it would undergo shattering, and in the spaces thereby opened there would be passageway for the metamorphosing solutions emanating from the minette magma.

ACKNOWLEDGMENTS.—The writer gratefully acknowledges indebtedness to A. C. Spencer, C. S. Ross, W. T. Schaller, and R. C. Wells, of the Geological Survey, and especially to A. W. Pinger, of the New Jersey Zinc Company, who have critically read this manuscript and given much helpful advice.

EXPLANATION OF PLATE I

A. Coarse granitoid type. Ordinary light. ×35.
B. Coarse granitoid type. Crossed nicols. ×35.
C. Fine-grained stony type. Ordinary light. ×35.
D. Fine-grained stony type. Ordinary light. ×35.

PLATE I

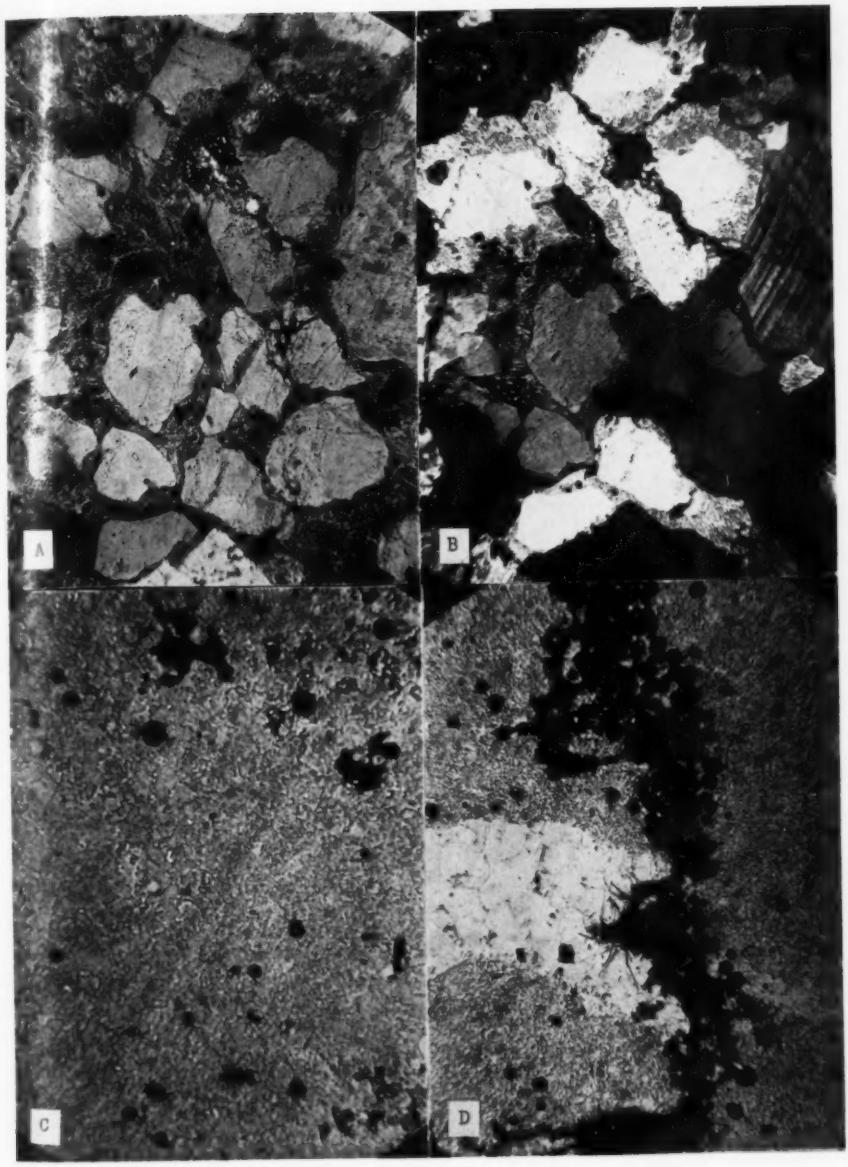

PLATE II

EXPLANATION OF PLATE II

A. Contact breccia type. Ordinary light. ×35.

B. Contact breccia type. Crossed nicols. ×35.

C. Pegmatite inclusion in minette, 400-foot level. The lower left-hand corner shows a chilled-border phase of the minette with small crystals of augite in a fine-grained groundmass. The rest of the field shows a quartz-feldspar aggregate (pegmatite) with peripheral albitization. Crossed nicols. ×26.

D. Pegmatite inclusion in minette, 400-foot level. Another view of partially albitized pegmatite under higher magnification. The dividing of the interstitial albite into two zones, oriented with respect to the surrounding grain, is apparent. Crossed nicols. ×82.

SOLUTION AND STREAM PIRACY

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ABSTRACT

The unusual course of the South Branch Potomac River through the famous Smoke Hole in eastern West Virginia is explained as stream piracy brought about by underground solution of limestone. Other instances of such stream diversions are cited in support of this interpretation.

INTRODUCTION

The writer has long held the opinion that the part played by solution in the development of topography has not been given due consideration. The formation of water gaps and unadjusted valley forms has generally been regarded as the result either of superposition of streams upon deformed strata of unequal resistance or of antecedent streams maintaining their courses through upfolded rocks of varying resistance to erosion.

Many examples of subsurface stream piracy have been described, but in every case studied by the author the attitude of the limestone involved was horizontal or nearly so. The strata in which the Smoke Hole Valley in Pendleton and Grant counties, West Virginia, has been formed are highly folded and mashed. This valley, in the opinion of the writer, occupies a site where a subterranean passage has been opened up, and where further development of this passage by solution has brought about stream piracy of a large order.

THE SMOKE HOLE VALLEY OF WEST VIRGINIA

The "Smoke Hole" is a narrow gorge having high, precipitous walls and a length of more than 17 miles. The South Branch Potomac River here turns abruptly from a mature valley to enter the young gorge of the Smoke Hole (Fig. 1).

Study of the topographic maps of the area and investigation in the field afford evidence of an interesting and, heretofore, unappreciated geomorphic history. The valley of the present North Mill Creek is much wider at its narrowest part than the Smoke Hole Valley is in its widest portion. The divide between the South Branch Potomac and

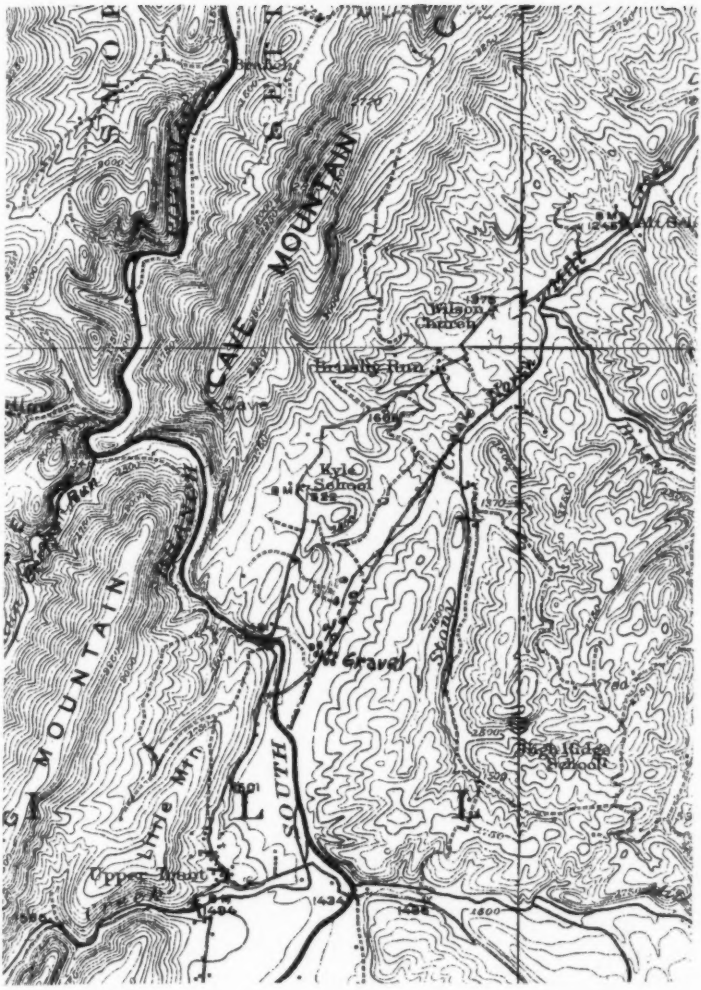

FIG. 1.—Present drainage of South Branch Potomac River. (From U.S. Geological Survey, Petersburg and Onego quadrangles, West Virginia. Scale 1:62,500; C.I. 50 feet.)

North Mill Creek is less than ½ mile from the present bed of the former stream. Furthermore, the divide is only about 50 feet above the bed of the South Branch. It would be a comparatively easy matter now to divert artificially the South Branch Potomac River through the valley of North Mill Creek (Fig. 2).

FIG. 2.—North Mill Creek Valley, looking northeast from divide at head of valley

If it be assumed that the valley of North Mill Creek is the former course of the South Branch Potomac River, stream-washed gravels and boulders in the divide area, an elbow of capture, terraces covered with terrace clays and stream gravels, and an entrenchment of North Mill Creek below the ancient valley floor would be evidence in support of the hypothesis of diversion. All these criteria of valley abandonment are present.

Stream gravels, cobbles, and even boulders were found on the inferred divide area and also on the terraces in North Mill Creek Valley (Fig. 3). Many of the specimens collected have been identified as the White Medina sandstone, which does not outcrop in the

vicinity of the present North Mill Creek Valley. The only possible way Medina sandstone gravels could have been deposited on the floor of North Mill Creek Valley is for them to have been carried by tributaries of the South Branch Potomac River into the main stream and thence to their present location. The same mature terrace soils (Monongahela) which are found abundantly in the South Branch Potomac Valley south of the Smoke Hole are also present in North Mill Creek Valley.[1]

FIG. 3.—Gravels from divide area in the abandoned channel of the South Branch Potomac River (see Fig. 1). Photo by Lucke.

Farther down (to the north) North Mill Creek has cut a channel in the Devonian shales and sandstones and, in places, has formed a narrow flood plain below distinct terraces. Some of these terrace tops have been formed on Oriskany sandstone and show marked beveling. All the prominent terraces, whether developed on the Oriskany formation or on the Middle Devonian shales, support stream gravels. Those near Petersburg have an elevation of about 1,200 feet. Thus there is a gradual slope of the ancient valley floor from the divide (1,400 ft.) between the South Branch Potomac drainage and the North Mill Creek drainage to the vicinity of Petersburg. The distance is about 14 miles and the slope approximately 14 feet per mile.

[1] B. H. Williams and H. M. Fridley, "Soil Survey of Hardy and Pendleton Counties, W. Va.," *U.S. Bur. Chem. and Soils, Series 1930*, No. 14 (1932).

It is highly improbable that a stream with so limited a drainage area as that of North Mill Creek could carry large cobbles and gravels over a wide valley floor, especially when some of these rocks are foreign to the drainage basin.

POSSIBLE INTERPRETATIONS OF SMOKE HOLE VALLEY

Why the South Branch Potomac should turn out of a valley for the most part underlain with shales, to take a course across ridges of resistant sandstone, is a problem that has puzzled geologists for many years. The generally accepted alternative explanations of such a situation are: (1) antecedent streams, (2) superposed streams, and (3) capture by a lateral tributary to a lower-level subsequent valley. As the deformation which brought about folding in this region is very ancient, antecedence from that period is quite improbable. If the stream has been entrenched from a peneplain which existed above the present ridges, it has been able to cut only a very narrow gorge through Cave Mountain, while mature valleys have been formed in equally resistant structures below the level of the supposed peneplain elsewhere in the region. The drainage area of the South Branch Potomac River is greater than that of the North Fork River. Nevertheless, the valley of North Fork where it passes through massive Medina sandstone before joining the South Branch Potomac River is no more youthful than the Smoke Hole Valley formed largely in limestone (Fig. 4).

If either of the hypotheses of antecedence or that of superposition is otherwise tenable, it fails to explain the presence of stream gravels, terrace clays, and terraces themselves in the North Mill Creek Valley. Finally, the development may have been caused by stream piracy. If the solution of the problem is to be stream piracy, the diversion of the South Branch Potomac across two ridges capped with Oriskany sandstone must be plausibly accounted for.

UNDERGROUND PIRACY BY BRIGGS RUN

There has been much faulting in this section, but the faults run parallel to, rather than across, the ridges. Hence, headward erosion along a fault zone is not a likely explanation. When, however, it is recalled that the resistant Oriskany sandstone is underlain by cal-

FIG. 4.—Smoke Hole Valley. The steeply dipping rocks are Helderberg limestone.

careous rocks to a depth of more than 1,000 feet, far below the present drainage levels, a satisfactory answer seems possible.

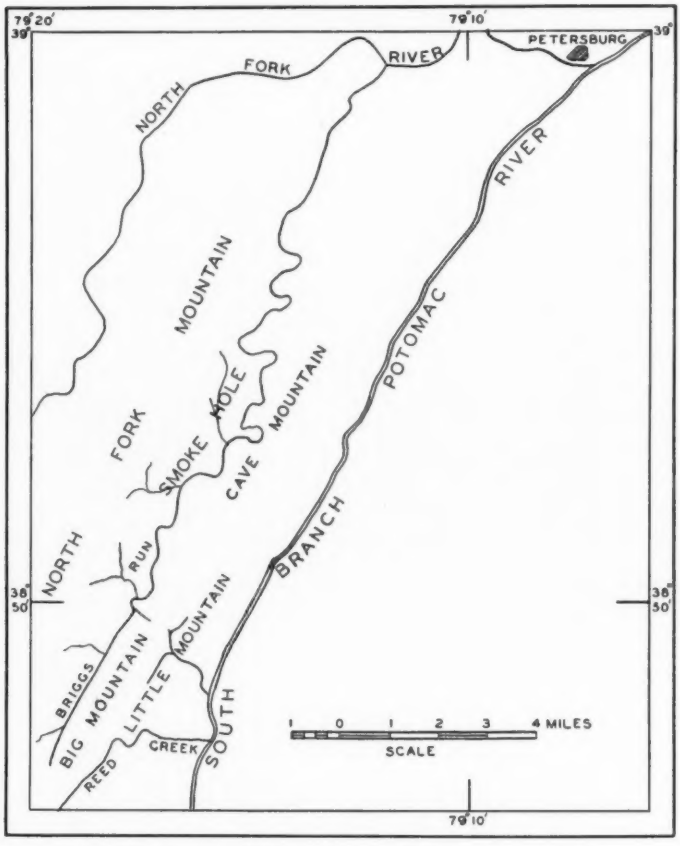

FIG. 5.—Precapture drainage of the South Branch Potomac River

Let it be assumed that a small stream west of Little Mountain at one time flowed eastward across the ridge along approximately the same course that the South Branch Potomac now follows into the Smoke Hole, but in the opposite direction (Fig. 5). This former stream would have joined the river about a mile north of Upper

Tract. It is further postulated that the stream cut deep enough into the anticlinal ridge of Little Mountain to reach the calcareous lower part of the Oriskany (Fig. 6). From this point solution took place through joints in the lower Oriskany to the underlying Helderberg and other limestones. From there the water seeped westward through limestone to existing solution channels in Cave Mountain and thence to Briggs Run. Briggs Run was then tributary to North

FIG. 6.—Solution channels in the lower Oriskany, in Little Mountain Gap

Fork River over the same course which the South Branch Potomac now follows and, of course, was at a lower level than the gap in Little Mountain.

Stream *A* (Fig. 7) became beheaded when the entire volume of the upper portion entered the subterranean passage. Since the stream was nearly at grade, the divide between the two parts of the former stream must have been very low. At times, when the South Branch Potomac was flooded, backwaters poured over the low divide into the sink hole in Little Mountain gap. It is not likely that this divide persisted for any great length of time. Soon the entire volume of the river flowed into the underground passage (Fig. 8).

The last step in the development of the present topography was the wearing-away of the present roof. Although the Oriskany sand-

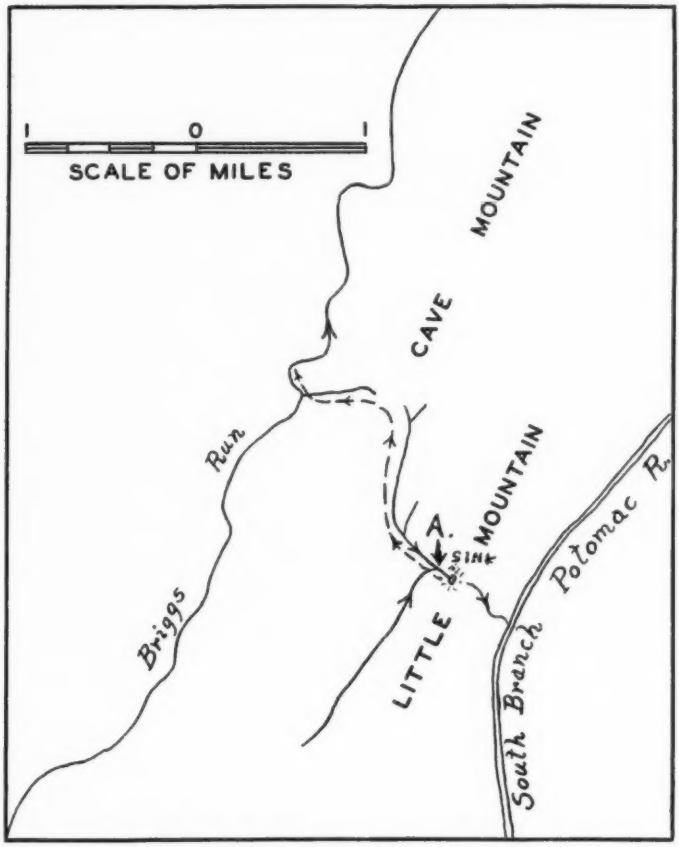

FIG. 7.—Drainage map of the Smoke Hole area at the time of capture of stream *A*. The broken line is the postulated course of the underground stream.

stone is comparatively resistant to weathering and erosion, it is to be noted that this rock in Cave Mountain is well jointed and could not persist as a cavern roof for a great length of time, geologically speaking. The name "Cave Mountain" is significant in this discussion.

There are many caves and caverns in this mountain, and large springs occur in the bed of the South Branch Potomac River in the Smoke Hole. One small stream is known to enter a sink hole in Cave Mountain and emerge 8 miles north of the entrance. Big Cave has been explored for several miles.

If the steps leading to the diversion of the South Branch Potomac by underground solution seem too hypothetical, it is pertinent that each of them is exemplified elsewhere in West Virginia.

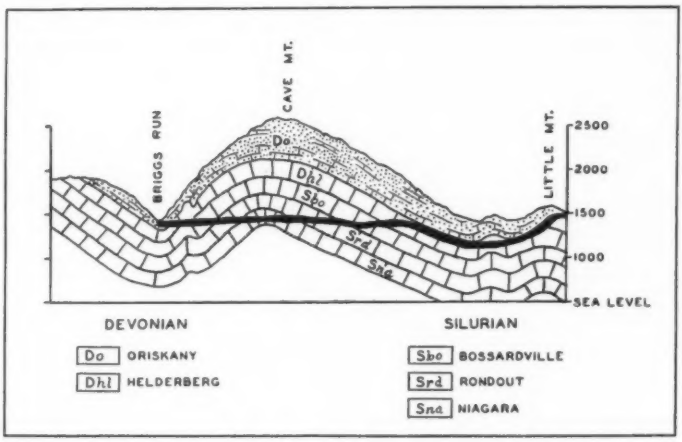

FIG. 8.—Northwest-southeast cross section through Cave Mountain. Vertical exaggeration about three times.

About 2 miles south of the gap through Little Mountain, mentioned above, Reed Creek has cut a gap through the same ridge to a depth of 500 feet. If it is to be argued that Reed Creek is a larger stream than the one west of Little Mountain, the answer is that its gap is also correspondingly deeper.

In eastern Hardy County, Lost River sinks below the Oriskany sandstone and flows underground for more than 2 miles. Although folding is not so pronounced here as it is in Cave Mountain, Lost River does not simply follow the dip of the limestone beds. Hydrostatic pressure is necessary to force the water of Lost River under the Oriskany through Sandy Ridge in the same manner that it

is assumed pressure was necessary to force water below the Oriskany in the syncline between the Little Mountain and Cave Mountain anticlines and up through the limestone to the bed of Briggs Run. It should be added that, to insure the formation of solution channels on as large a scale as has been indicated, it is necessary to accept Davis' theory of cavern development below rather than above the water table.[2]

OTHER CASES OF STREAM PIRACY BY SOLUTION

Hills Creek in Pocahontas County, West Virginia, flows under Droop Mountain for a distance of about 1½ miles. Droop Mountain has a synclinal structure and is capped with sandstone which overlies the massive Greenbrier limestone. Eventually the cavern roof will collapse and Hills Creek will flow through a gorge similar to the one in Cave Mountain through which the South Branch River now flows.

Many streams in Greenbrier County sink into limestone and, by subterranean routes, pass under sandstone ridges for many miles.

CONCLUSIONS

The unusual character of the course of the South Branch Potomac River through the Smoke Hole in eastern West Virginia is attributed to subsurface solution piracy by Briggs Run.

It is suggested that many cases of stream piracy formerly attributed to surface erosion were actually initiated by underground solution of calcareous strata. Many water gaps, ascribed to superposition, may rather have been formed by similar stream piracy.

ACKNOWLEDGMENTS.—The writer wishes to acknowledge the aid and suggestions of Dr. O. D. von Engeln, Dr. S. L. Galpin, and members of the West Virginia Geological Survey.

[2] W. M. Davis, "Origin of Limestone Caverns," *Bull. Geol. Soc. Amer.*, Vol. XLI (1930), pp. 475–628.

SOME GARNET CRYSTALS FROM CALIFORNIA

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ABSTRACT

Numerous large and well-developed crystals of almandite garnet were found in boulders of a banded diorite at the south end of the San Joaquin Valley, California. The crystals are characterized by numerous inclusions of feldspar, which give them a curiously spotted appearance. Frequently they are separated from the normal diorite by a zone of pure feldspar. They are either phenocrysts or were formed by replacement of the diorite shortly after its intrusion into a series of metamorphosed sediments.

Recently the writer was given some fine specimens of large garnet crystals, which showed such unusual characteristics that it seemed worth while to investigate their occurrence. Accordingly a trip was made to the locality and material collected for further study, the results of which are here offered. These garnets occur in the Tehachapi foothills at the extreme southern end of the San Joaquin Valley, in boulders in the alluvial fans and stream bed. They were first discovered by L. M. Clark and Gerald Henny, of the Shell Oil Company, a number of years ago and are familiar as specimens to a number of geologists, but so far as known there is no written description of their occurrence, although Melhase[1] has mentioned the locality. The writer wishes to thank Dr. William J. Miller, of the University of California at Los Angeles, and Mr. C. M. Carson, of the Consolidated Oil Company, for directions for reaching the locality. The garnets are on the property of the Tejon Ranch, about twelve miles east of Rose Station, and permission to collect is readily obtained at the ranch headquarters. The exact locality is in the fan and creek bed of the second small valley west of El Paso Creek, and the garnets seem to be rather closely limited to this one drainage channel.

The general geology of the region has been described by Hoots[2] approximately as follows: There is a series of Tertiary sediments,

[1] John Melhase, "Some Garnet Localities of California," *Mineralogist*, Vol. III (1935), p. 8.

[2] Harold W. Hoots, "Geology and Oil Resources along the Southern Border of San Joaquin Valley, California," *U.S. Geol. Surv. Bull. 812* (1930), pp. 243–332.

which form the floor of the valley here under the alluvium, and which lie with normal depositional contact on a basement of metamorphic and igneous rocks. The dip of these sediments near the Tejon Ranch is 10°–15° northward. The contact between them and the basement rocks is probably about at the base of the foothills, but was not observed here, owing to the heavy covering of alluvial material in the form of gently sloping fans. These fans show two distinct levels, 50–100 feet apart, with the streams incised into the bedrock beneath the lower fan level. Hoots[3] records the occurrence of two notable uplifts, one in late Pliocene or early Pleistocene, and another at the end of the Pleistocene, which would account adequately for these physiographic features. The first rock seen in place is a strongly banded schist, apparently a series of metamorphosed sediments, which strikes approximately E.–W., and dips 75°–80° S. Continuing upstream this schist begins to change in character, becoming increasingly injected with dioritic material, until within a mile or less from the plain, the rock is essentially a streaky diorite. This diorite shows two distinct phases, both plainly gneissic, with the schistosity paralleling that of the meta-sediments. One phase is rich in hornblende, so much so as to be almost black, and the other is a more nearly normal diorite. The light phase is quite definitely younger than the dark, as it occurs repeatedly in dikes and stringers in the latter, and the dark appears as irregular and angular inclusions in the former.

It was hoped that by following the float upstream, the garnets might be found in bedrock, but in spite of careful search both in the stream bed and in the infrequent outcrops on the valley walls, no occurrence *in situ* was discovered. Garnet-bearing boulders were found for about two miles upstream from the head of the fan and then disappeared, showing the upper limit of their occurrence. At and near this point, the boulders were quite angular and often large, so that clearly they had traveled only a short distance from their source. Elsewhere downstream the boulders invariably showed abundant signs of transportation, indicating that the garnets must have come from a short section of the canyon. Moreover, the side canyons here and lower down showed no garnet float, so that ob-

[3] *Ibid.*, pp. 318 and 321.

viously the occurrence must have been limited to a relatively short and narrow zone in the gneissic diorite. Enough material was found to indicate that the garnets occur most commonly in the light rock, although a fair number were observed in the dark.

The garnets are dark reddish brown in color, occasionally transparent in part, but more commonly translucent to opaque. They occur ordinarily as well-shaped isolated crystals, but a few definite veins of garnet were noted, cutting across the schistosity of the diorite and appearing in either phase. These veins show no trace of mechanical deformation.

The crystals range in size from grains $\frac{1}{4}$ inch in diameter up to a maximum of $3\frac{1}{2}$ inches but the average size is between 1 and 2 inches across. The dominant form is the trapezohedron *n* (211), this being the only form on many of the crystals. A number, however, have one or more small dodecahedral faces, and usually many small facets parallel to these, on the trapezohedron. Their surfaces are sometimes very smooth but much more commonly pock-marked by grains of other minerals, as if the garnet in growing had partly enveloped these. Less commonly, the garnet forms irregular masses which have no crystal outline, but are nevertheless apparently single individuals. Often, though not invariably, the crystals are surrounded by a narrow white zone in marked contrast to the normally speckled diorite, so that they stand out even more conspicuously than usual in the matrix. The two crystals in the photograph (Fig. 1) show this zone quite plainly. Most of the crystals themselves are not pure garnet, but are filled with inclusions of feldspar in irregularly rounded and corroded grains, which in a few instances may make up as much as one-half to two-thirds of their total volume. Small grains of magnetite also occur thinly scattered through the garnets. In the dark facies of the diorite, the garnets are in general much freer from inclusions and may in some cases be essentially pure. In at least two cases, there is a definite zonal structure with a normal feldspar-filled core, a band of nearly pure feldspar, and, on the outside, a thin layer of nearly pure garnet.

The garnet veins are of two sorts: first, nearly solid, granular garnet; second, lines of small crystals, like strings of beads, set in a broader zone of white and occurring usually in the light rock. The

garnet crystals in these veins frequently show feldspar inclusions, just as in the larger garnets. Some of them also show patches of a greenish color, mottled with red-brown, suggesting partially resorbed hornblende. One of the second-type veins apparently intersects two of the larger garnets, which in this instance do not show many good crystal faces but are rather irregular in outline. The

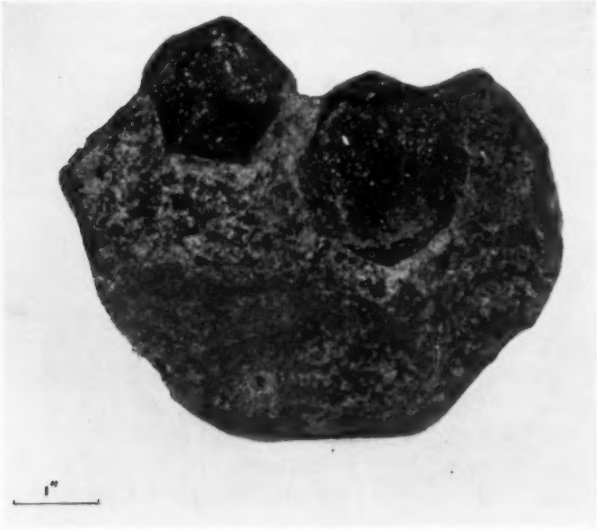

FIG. 1

transection of one of the large garnets by the vein is not obvious and in fact was observed only after the polishing of a plane surface on the specimen. It is shown as an invasion of the garnet by feldspar along the general line of the vein. Actual garnet of the vein does not appear in the intersecting part of the vein.

Some of the irregular garnets, distant from veins, showed similar evidence of later feldspar development. In these cases the garnet surfaces are embayed irregularly or penetrated by wedgelike projections of feldspar. Furthermore, they showed no crystal facets along such irregular contacts. Considering the strong crystallizing power

of garnet and the fact that we find well-shaped garnet crystals of all sizes in the same occurrence, we should expect here also good crystal forms if these garnets owed their external form to normal growth.

Close inspection of some of the larger garnets, after grinding down and polishing, showed that their substance is not always uniform, but often made up of indefinite patches of a darker color in a lighter background. Both shades of garnet carry feldspar inclusions. In general, this patchy distribution of shades rather vaguely suggests a granulation and recementing of the original garnet material, as the areas are very poorly defined. In one instance, however, a large garnet crystal is definitely veined by lighter garnet, which has apparently eaten into and cemented the fragments of the earlier and darker mineral, and which has grown out in parallel orientation with the latter, as shown by the development of external crystal faces parallel with those of the original crystal. The variation in color of the garnet was not observed in the thin sections.

An interesting epitome of the modes of occurrence is found in the specimen shown in Figure 2, where a garnet in the light-colored rock appears full of feldspar grains; another, just at the contact of light and dark, contains abundant feldspars in the part enclosed by light rock, while the dark part is nearly free from them. The garnet in the light rock shows a partial zone structure as described above. On the same specimen, though not shown in the photograph, a thin vein of garnet cuts across the structure. The rock itself has the typical streaking of light and dark diorite characteristic of the large-scale occurrence in the field.

In thin sections of the diorite both phases are seen to be essentially the same, except in the relative proportions of the minerals. They are coarse grained, and sections may or may not show the gneissic structure depending on their orientation. The minerals present are a basic plagioclase feldspar (An_{65}) and common hornblende, with very minor amounts of magnetite in small rounded grains or crystals. Practically no other minerals were noted in any of the sections. In the light phase, feldspar is usually somewhat in excess of hornblende; in the dark, hornblende may make up 70 per cent or more of the total. Sections of the garnets show them to be remarkably fresh, with only a few traces of alteration in even the

most weathered specimens. The feldspar of the inclusions is identical with that in the surrounding rock, and appears as rounded, cor-

FIG. 2

roded, and clearly residual fragments. The accompanying sketch, Figure 3, shows a typical garnet-feldspar relationship, as taken from a hand specimen, on a scale large enough to see with a hand lens. This same pattern is duplicated abundantly on a microscopic scale in the thin sections. Magnetite occurs in the garnet in about as

great abundance as in the diorite and appears to be entirely untouched. Where a white zone surrounds a garnet, it is seen to be composed of essentially the same feldspar with an occasional magnetite grain. The garnet in thin section is pale pink, entirely isotropic, and shows abundant fractures. Usually one direction of fracture is predominant, but this does not appear to be parallel to any definite crystallographic direction and may be due to continuing

FIG. 3

development of schistosity in the diorite. Carefully picked fragments, free from feldspar or magnetite, gave a specific gravity of 3.80 and index of refraction 1.76±. Qualitative chemical tests revealed abundant iron, considerably less aluminum, and a small amount of calcium. No detectable amounts of magnesium, manganese, or titanium were present. This identifies the variety as a rather iron-rich almandite.

ORIGIN

The diorite in which the garnets occur clearly forms an injection gneiss along a zone of contact with the meta-sediments, and its dark phase, farther away from the contact, may represent the effect of digestion of some of this material. As stated before, the light

phase is definitely younger than the dark, and the garnets, in part at least, are younger than either. This is definitely shown by the crosscutting garnet veinlets, which traverse both phases of the diorite. With this sequence established, it would seem certain that the vein garnet at least must have been formed by metasomatic replacement of essentially solid rock. The evidence for the character of the large garnets is by no means so clear. There are two alternative hypotheses for their manner of formation. They may be phenocrysts formed in the original magma, or they may have been formed by replacement of the diorite after its consolidation.

In the first case the lack of distortion of the crystals may be explained by assuming that the gneissic structure of the rock was produced before its solidification. Under such conditions, the garnets would be floating in a highly viscous liquid and would not be subjected to differential strain. The development in them of a linear fracturing suggests that movement of the diorite may have continued for at least a short time after its effective consolidation. The blotchy color of the garnets and the evidence of one which was definitely fractured, then corroded and recemented by a later garnet-feldspar mixture, reinforce this suggestion, but of course also imply a replacement character for the later garnet. Phenocrysts filled with inclusions of country-rock minerals are not unknown,[4] and it is quite conceivable that these inclusions are merely earlier-formed grains of the rock minerals mechanically included in the growing garnets. During this growth, the inclusions of hornblende may have been entirely destroyed, while the feldspars were resorbed only in part. The presence of a hornblende-free zone about these crystals and development of additional feldspar here may be explained by a process of local magmatic segregation. The apparent replacement of garnet by feldspar in the case of those grains with irregular outline strengthens this theory of origin by emphasizing the earlier date of the garnet.

If, on the other hand, we consider that the garnets were formed by replacement, we must assume here also a rather complex series of events, which may have been somewhat as follows: Diorite magma

[4] William J. Miller, "Precambrian and Associated Rocks near Twenty-nine Palms, California," *Bull. Geol. Soc. Amer.*, Vol. XLIX (1938), p. 429.

was intruded into a series of meta-sediments, forming an injection gneiss at and near the contact and being contaminated with a decreasing amount of foreign material with increasing distance from it. This foreign material was more or less completely resorbed by the magma, forming a dark facies, which was divided and transected by the purer diorite, which, as shown in the field, was distinctly later. In the process of consolidation, the diorite developed a gneissic structure. Closely following this consolidation or possibly in the final stages of it, migrating solutions developed well-formed garnet crystals here and there in the mass. A slight movement of the matrix after their formation would account for their occasional granulation. The garnets were developed as metacrysts, and in process of formation used up all the hornblende in the neighborhood, leaving an impoverished zone about them in many cases. The feldspar of the original rock was not as a rule completely absorbed but survived as numerous residual grains in the garnets. Magnetite was not affected at all. There was enough redistribution of material in this replacing process to develop additional feldspar to fill in the space left by the removal of hornblende in the surrounding zone. This follows, since there is no evidence of open space and there must have been hornblende originally in this zone. Accordingly the solutions must have been capable of depositing both garnet and feldspar. One portion of this solution was later in arriving at some localities and formed definite veins of garnet and feldspar. Some of these veins intersected earlier garnets and in part replaced them with feldspar. In other places, similar solutions soaking through the rock, but without forming veins, attacked and partially replaced some of the large garnets, with the formation of second-generation garnet and feldspar. This process will account for the irregular outlines and mottled or brecciated appearance of such grains.

From the assembled evidence the writer is unable to reach a definite conclusion as to which theory is correct in the case of the large garnets. The vein garnets, however, and the secondary cementing garnet material must be of replacement origin. In either case, it is most probable that the garnets were formed within a relatively short time interval either before or after the consolidation of the diorite.

EVIDENCE OF THE AGE OF A CRYSTALLINE LIMESTONE IN SOUTHERN CALIFORNIA

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ABSTRACT

The recognition of a Mississippian fossil coral in the crystalline limestones of the Winchester quarry, near Hemet, California, extends the known distribution of the Mississippian rocks in California, definitely indicating the presence of Mississippian seas in the southern California area.

INTRODUCTION

The crystalline formations of pre-Cretaceous age in southern California have been rather thoroughly searched by numerous workers for fossil material by which their ages can be determined. To date, little fossil material has been recovered, and that which has been found is fragmentary. Recently a tetracoral was collected in the talus at the base of a large marble bed in the upper quarry of the Winchester magnesite mine near Hemet, California. This is, as far as the writer is able to determine, the first identifiable fossil collected from crystalline formations in southern California south and west of the San Andreas fault.

DESCRIPTION AND IDENTIFICATION OF THE CORAL

The fossil consists of a reasonably well-preserved pair of corallites whose affiliation with the *Tetracoralla* is at once evident. The specimen measures $1\frac{1}{2}$ inches in length, and each calyx is approximately $\frac{1}{2}$ inch in diameter. The fossil was sectioned transversally and longitudinally and polished. The specimen was then submitted to the United States Geological Survey, where the coral was identified as a member of the cyathophylloid group, of Mississippian age. The following is quoted from the letter of Dr. John B. Reeside, Jr.,[1] geologist in charge of the Section of Paleontology and Stratigraphy of the United States Geological Survey:

> The coral . . . . was examined by a number of specialists in Paleozoic faunas, who agreed that the age of the fossil would be either Devonian or Mississippian.

[1] Dated February 15, 1938.

It was then examined more closely by Dr. G. H. Girty, of the Geological Survey, and Dr. G. A. Cooper, of the National Museum, who consider the form to be a cyathophylloid coral of Mississippian age. As the Paleozoic corals have not been much studied, the classification and use of them for age assignments are not very satisfactory, and no closer determination than that given is deemed justifiable.

CORRELATIONS AND SIGNIFICANCE OF THE AGE DETERMINATION

In the area of southern California, widespread and widely separated masses of crystalline limestone occur. Within 1–5 miles of the Winchester quarry are numerous scattered outcrops of limestone of similar type; it seems probable that they are correlative of the series in which the coral was found. Besides those of the immediate vicinity, marbles found in the quarries of the Portland cement works at Crestmore and Colton, as well as those in isolated areas between Colton and Winchester, may be of the same period. Beyond this, correlations are not justified, even where lithology is similar.

Finding a coral of Mississippian age extends the known transgression of the Mississippian seas—a fact which has long been suspected and which has long been known for much of the Great Basin province.

PREVIOUS AGE ASSIGNMENTS AND CORRELATIONS OF CRYSTALLINE UNITS IN SOUTHERN CALIFORNIA

Many workers have offered suggestions on the age of crystalline units in southern California. In 1914 Dickerson[2] suggested a possible Paleozoic age for the marbles found in the basement complex of the Antelope Valley at the northern base of the San Gabriel Range, northeast of the San Andreas fault. Vaughan[3] reported that Noble found, in the San Gabriel Mountains, limestone in which there were a few poorly preserved gastropods which appeared to resemble forms found in Ordovician limestones of eastern California.[4] Vaughan con-

[2] Roy E. Dickerson, "The Martinez Eocene and Associated Formations at Rock Creek on the Western Border of the Mohave Desert Area," *Univ. Calif. Pub. in Sci., Bull. Dept. Geol.*, Vol. VIII (1914), pp. 289–98.

[3] F. E. Vaughan, "Geology of San Bernardino Mountains North of San Gorgonio Pass," *Univ. Calif. Pub. in Sci., Bull. Dept. Geol.*, Vol. XIII (1922), pp. 319–411. On p. 362 Vaughan quotes Noble through a letter from R. E. Dickerson in 1917.

[4] Upon inquiry regarding this determination, Dr. Noble replied by letter on March 21, 1938, as follows: The statement ". . . . regarding the Ordovician gastropods is

cluded that the limestones of the San Bernardino Range are Cambrian or Ordovician, purely on lithologic grounds and on the probabilities based on the findings of workers in areas in the Great Basin where some fossils have been recognized. Woodford and Harriss[5] found sufficient fossil material to place tentatively a part at least of the Furnace limestone of Blackhawk Canyon in the San Bernardino Mountains in the Mississippian. Miller[6] summarized the statements of all previous workers and concluded that the age of the Placerita formation of crystalline marbles and associated types of the San Gabriel Range is probably pre-Cambrian and that other units of different lithology, such as those described above, are younger. Simpson,[7] working in the Elizabeth Lake quadrangle, north and west of the San Gabriel Mountains, found two crystalline units containing marbles, the older of which he correlated with the Rand schist of Hulin,[8] assigned to the pre-Cambrian, and the younger, to the Paleozoic or Mesozoic.

Nearly all of the opinions presented above are based on lithology, and until recently no one has gone so far as to suggest correlation of all the crystalline marble units of southern California in one epoch of sedimentation. However, Oakeshott[9] in a recent paper, on purely

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correct, but needs explanation. I did not find the supposed fossils. Professor Schuchert was visiting me . . . . in 1915. He went . . . . to examine the crystalline limestone injected by granite . . . . at the mouth of Rock Creek. He came back and said that he noticed obscure forms in the limestone that *looked* something like the big gastropod that is so abundant in the Ordovician Pogonip dolomite in the Death Valley region. . . . . Neither Schuchert nor I were at all certain that the 'fossil' forms were really fossils. That is why neither of us went on record or published anything about them. . . . ."

[5] A. O. Woodford and T. F. Harriss, "Geology of Blackhawk Canyon, San Bernardino Mountains, California," *Univ. Calif. Pub. in Sci., Bull. Dept. Geol.*, Vol. XVII (1928), pp. 265–304.

[6] William J. Miller, "Geology of the Western San Gabriel Mountains of California," *Univ. Calif. at L.A. Pub. in Math. and Phys. Sci.*, Vol. I (1934), pp. 1–114.

[7] E. S. Simpson, "Geology and Mineral Deposits of the Elizabeth Lake Quadrangle, California," *Calif. Jour. Mines and Geol.*, Vol. XXX (1934), pp. 371–416.

[8] Carleton D. Hulin, "Geology and Ore Deposits of the Randsburg Quadrangle, California," *Calif. State Mining Bur. Bull. 95* (1925), pp. 1–152.

[9] Gordon B. Oakeshott, "Geology and Mineral Deposits of the Western San Gabriel Mountains, Los Angeles County," *Calif. Jour. Mines and Geol.*, Vol. XXXIII (1937), pp. 215–49.

lithologic bases, suggests the correlation of the Placerita formation of the San Gabriel Mountains with the Furnace limestone of Blackhawk Canyon; and it has also been suggested that the Pelona series[10] is correlative. Essentially, then, Oakeshott would place all of the marbles of southern California in the Carboniferous on lithologic grounds. While this correlation is admitted to be without fossil evidence, Oakeshott seems to think it very probable.

The writer has visited all the marble localities in southern California which have been described in the literature and some that have not been described. Lithologically, the marbles and associated types of the Placerita formation of the San Gabriel Mountains are so different in appearance from the Furnace limestone and from the marble of the Winchester quarry that it would seem illogical for anyone to even suggest their correlation on lithologic bases. The Pelona series is also different but is more like the Placerita than any other formation of the region, although their correlation on lithologic grounds would be pure speculation. It seems, therefore, since individual workers cannot agree on what constitutes similar lithology, that it would be better if correlations over many miles were not attempted, where lithologic evidence alone is available.

ACKNOWLEDGMENTS.—The writer wishes to thank Mr. V. D. Myers, of Santa Monica, California, who first found the coral and called it to the writer's attention. The kindnesses of the various members of the United States Geological Survey in the identification of the fossil are gratefully acknowledged.

[10] Oscar H. Hershey, "Some Crystalline Rocks of Southern California," *Amer. Geol.*, Vol. XXIX (1902), pp. 273–90.

DISCUSSION: "PILLOW LAVAS" OF BORABORA SOCIETY ISLANDS

H. E. McKINSTRY
New York City

J. T. Stark[1] presents a very instructive description of ellipsoidal structures in lava flows and dikes which he studied on one of the Society Islands. He explains these structures as due to coalescing of gas bubbles and billowing of the lava during vesiculation. In this case the ellipsoidal structures came into being within the flow or dike while the material was in place and was beginning to solidify.

Since Mr. Stark does not imply that this explanation covers the origin of all pillow lavas, there is no inherent reason for not accepting it for the particular structures which he describes. But it is evident that the origin of these ellipsoids was quite different from that of ordinary or "typical" pillows; and from Stark's descriptions and illustrations it is clear that they are also different in appearance, as the following notes will indicate.

I was one of a group that studied in detail the pillow lavas of the Porcupine district, Ontario, in the course of an investigation directed by Dr. L. C. Graton. The Porcupine pillows are typical of those which I have seen in pre-Cambrian lavas in numerous localities in Canada[2] and Western Australia and are similar to those in Tertiary or younger lavas in Bali and eastern Java. Furthermore, they are similar to those of the New Jersey Triassic described in J. Volney Lewis' classic paper and to the Paleozoic pillow lavas in Newfoundland described by Edward Sampson.

The pillows in the Porcupine district have dense rims, and the line dividing one pillow from the next is clearly marked. Their upper surfaces are usually rounded (convex upward), but their lower sur-

[1] "Vesicular Dikes and Subaerial Pillow Lavas of Borabora, Society Islands," *Jour. Geol.*, Vol. XLVI (1938), pp. 225–38.

[2] An excellent description of pillow lavas in Quebec is given by Cooke, James, and Mawdsley in "Geology and Ore Deposits of the Rouyn-Harricanaw Region," *Canada Dept. Mines Geol. Surv. Mem. 166* (1931), pp. 40–50.

faces conform to the shape of the pillow or pillows lying underneath. In many cases the bottom of a pillow is a downward-pointing cusp or a plug like the stem of a mushroom that fits between the curved surfaces of two underlying pillows. In numerous instances spaces between the pillows are filled with fragmental material (palagonite), and in some cases a layer of palagonite surrounds each pillow.

In some stratigraphic units the pillows are characterized by amygdules and in others by spherules. A pillow of the amygdaloidal type has a dense chilled margin, within which is an annular zone of amygdules. These in some cases are elongated parallel to the radius of the pillow, but the center of the pillow is normally free from amygdules, or nearly so, and could never have been hollow like the Borabora forms. A pillow of the spherulitic (variolitic) type likewise has a dense rim, and within this the spherules become larger and more closely spaced toward the center until the center itself consists almost exclusively of spherulitic material. Under the microscope the spherules show characteristic plumose texture. Amygdules are sparse or absent in the spherulitic pillows.

The features described above indicate that each pillow must have formed before the one above it acquired its shape; that each pillow is a distinct entity and, in a sense, an individual flow which cooled within its own crust; that the ellipsoidal shapes could not have come into being while the material was in place as part of a thick mass of lava; and that formation of vesicles was not an essential part of the process.

There is no direct evidence as to whether these pillows formed under air or under water, but it is true that some of the pillow-lava horizons in the Porcupine district and at Kalgoorlie, Western Australia, rest on or are covered by carbonaceous slates and cherts which are pretty clearly sedimentary, and pillow lavas interbedded with marine cherts have frequently been described in the literature. Sampson, after an exhaustive review of the subject, concludes that in general "a thick series of pillow lavas covering a wide area and free from pahoehoe and massive flows is in all probability a subaqueous flow."[3] The Society Islands structures, inasmuch as they

[3] Edward Sampson, "The Ferruginous Chert Formations of Notre Dame Bay, Newfoundland," *Jour. Geol.*, Vol. XXXI (1923), p. 577.

differ from "typical" pillow lavas, do not refute Sampson's conclusion.

It seems as though there ought to be separate names to distinguish between structures of the Borabora type and "typical" pillow lavas. This is said not merely by way of quibbling over terminology but because "typical" pillows are pretty certainly diagnostic of extrusive origin and are believed by many to indicate subaqueous extrusion. Unless they are distinguished from other forms which can originate in dikes and in flows under air, they lose their value as criteria.

Quite apart from the merits of other portions of his interesting paper, Mr. Stark has gone a long way toward clarifying a problem by presenting a clear description of a type of ellipsoidal structure which bears a strong resemblance to "typical" pillow lava, but can be distinguished from it with the aid of his description, and is a sign of quite different conditions.

DISCUSSION: PILLOW LAVAS

J. T. STARK
Northwestern University

Mr. H. E. McKinstry has very kindly sent me the manuscript of his comments on my recent paper in this *Journal* entitled "Vesicular Dikes and Subaerial Pillow Lavas of Borabora, Society Islands."[1] Without objecting in any way to the descriptions of the pillow-like structures or the suggested explanation of their origin, Mr. McKinstry points out that the term "pillow lava" applied to these structures is misleading and suggests that " 'typical' pillows are pretty certainly diagnostic of extrusive origin and are believed by many to indicate subaqueous extrusion." The writer is in hearty agreement with any attempt toward a more precise nomenclature, and, if there is a consensus among geologists to restrict the term "pillow" to those structures which have been formed in more or less direct connection with water, he will gladly qualify his descriptions of the Borabora structures and call them pillow-like or omit the use of the word "pillow" entirely, rather than overburden an already crowded nomenclature with a new term. Mr. McKinstry's views are so clearly stated and his contention so reasonable that no comment was thought necessary.

Since receiving Mr. McKinstry's manuscript, however, the writer has had the privilege of discussing the question with Dr. H. G. Stearns, who feels strongly that the use of the term "pillow" is incorrect for any structures that do not conform to his definition of "true pillows," given in the *1937 Proceedings of the Cordilleran Section of the Geological Society of America*. True pillows, he states, "consist of spheroidal and ellipsoidal ball-like masses of lava, coated with glass and generally detached from each other with fragmental glassy material in the interstices . . . . pillows form only as a result of excess extraneous steam; hence are caused by lava either entering water or being spread over or intruded into moist ground."[2] Dr.

[1] Vol. XLVI (1938), pp. 225–38.

[2] Pp. 252–53.

Stearns also points out in the paper and in conversation that many descriptions cited as pillow lavas are not pillow lavas as he defines them. It is at his suggestion that this additional note on use of the term is being written.

Since both McKinstry and Stearns are concerned about the use of the word "pillow," it may be well to call attention to its past use. As reviews of the literature with extensive bibliographies are already in print, only brief references to these résumés will be necessary.

Johannsen concludes from a review of the literature that the association of pillows with sediments suggests their subaqueous origin, noting, however, other theories that pillows "are due to concentration (Bonney), agglomeration or brecciation (Winchell, Williams, Lawson), spheroidal weathering, contraction of lava, and rolling (Gregory and Cole), pahoehoe-like rolling (Ransome), dynamic movements in columnar structure (Smith)."[3]

Van Hise and Leith, after a review of the literature, conclude that "ellipsoidal structure is both subaqueous and subaerial in its development . . . . that it is likely that a part of the structures in the Lake Superior region are of subaerial origin."[4]

Lewis in his definitive paper on the origin of pillow lavas reviews ninety-eight descriptions of such structures in the literature between 1834 and 1914. Of these, thirty-two suggest subaqueous origin, several indicate origin unknown, and *fifty-two* imply no necessary association with water. Lewis states: "It seems safe to conclude that neither the presence nor the absence of water, *per se*, can be predicated as particularly favorable to the formation of this structure."[5]

It seems scarcely necessary to continue references to articles and texts in which the term "pillow" has been used synonymously with ellipsoidal to describe shapes of structures in lavas, since the only point in making such references is to indicate how variously the term "pillow" has been used. In view of the fact that "pillow" was originally used to describe shape and has been used so commonly by many

[3] Albert Johannsen, *A Descriptive Petrography of the Igneous Rocks*, Vol. I (Chicago: University of Chicago Press, 1931), p. 224.

[4] *Mon. 52, U.S. Geol. Surv.* (1911), pp. 511–12.

[5] J. Volney Lewis, "Origin of Pillow Lava," *Bull. Geol. Soc. Amer.*, Vol. XXV(1914), p. 652.

writers without reference to an origin conforming to Stearns's definition of a "true pillow," it would seem to the writer that the term is not genetic but simply a morphologic term for ellipsoidal structure. If we are now to restrict the use of "pillow" to structures that, according to Stearns, "form only as a result of excess extraneous steam, hence are caused by lava either entering water, or being spread over or intruded into moist ground"—then we must face the fact that confusion may be increased rather than decreased by adopting a genetic meaning for a term that previously has been widely used in a morphologic sense.

For this reason the writer thought it best not to invent a new term for the Borabora structures, but to point out their difference in origin from subaqueous ellipsoidal structures by the qualifying "subaerial pillows." In his description of the Borabora lavas there was no intention to imply that the explanation of their origin should be applied to other areas, since in every other place where he has observed such ellipsoidal structures their origin has seemed to be probably subaqueous.

In conclusion, attention may be called to a very interesting new exposure of pillow lavas in the Ely greenstone of the Vermilion Iron Range, Minnesota. Since the excellent photographic illustrations and descriptions by Clements and by Van Hise and Leith appeared in *Monographs 45* and *52* of the United States Geological Survey, many of these classic outcrops have been more or less covered by the growth of underbrush and lichens, and many of the easily accessible outcrops in the vicinity of the town of Ely, Minnesota, are obscured or hidden by building and civic developments. Last summer an air shaft was being drilled for the Zenith iron mine just northeast of Ely by J. B. Newsome, of the Idaho Maryland Mines Corporation of San Francisco, California. A rotary-shot drill was used and a depth of 720 feet had been reached, about half that of the contemplated shaft, through the ellipsoidal lavas of the Ely greenstone formation of Keewatin age. Drill cores 5 feet in diameter and 10–14 feet long were being taken from the shaft and rolled into an adjoining field. These now provide a spectacular new exposure of pillow lavas for the visiting geologist. The core sections show excellent examples of pil-

low structures, both in cross section and around the semi-polished cylindrical surfaces (Figs. 1 and 2).

FIG. 1.—Pillow lava. Cross section of 5-foot-diameter rotary drill core, Ely greenstone. Flows overturned and dipping to left 50°, top to right.

FIG. 2.—Pillow lava. Drill core showing flattened bottoms of pillows and convex upward top surfaces, Ely greenstone.

These pillows appear similar in every way to those described by Dr. McKinstry in the Porcupine area. The dense rims clearly mark

the boundaries of the pillows (Fig. 3), their upper surfaces are rounded and convex upward (Fig. 2), the lower surfaces conform to

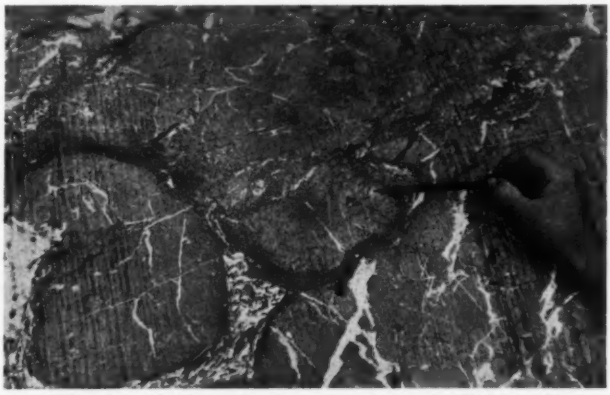

FIG. 3.—Pillow lava. Drill core showing denser rims and radiating vesicles marking the boundaries between pillows, Ely greenstone.

FIG. 4.—Pillow lava. Drill core showing downward-pointing stem between two underlying pillows, Ely greenstone.

the shape of the structures beneath, and the downward-pointing cusp or pluglike stem fitting in between two underlying pillows is a characteristic feature (Fig. 4).

REVIEWS

The Tetons: Interpretation of a Mountain Landscape. By FRITIOF FRYXELL. Berkeley: University of California Press, 1938. Pp. xiv+73; pls. 13; figs. 2; folding map. $1.50.

The most striking mountain peaks in the United States, exclusive of Alaska, are unquestionably those clustered close together in the short Teton Range of Wyoming. Rather recently the establishment of Grand Teton National Park and the building of good roads have made easily accessible these magnificent specimens of mountain-fashioning, previously viewed and appreciated only by a favored few. The author of this little book started his geologic studies in this region before the National Park was authorized, and in the course of many summers climbed all the principal peaks, many of them being notable first ascents. (For accounts of these hours of vigorous exercise and exploration the reader may be referred to Fryxell's *The Teton Peaks and Their Ascents* [1932]; the present volume modestly makes no mention of the earlier one, or of his more technical publications.)

Nearly every page breathes the splendid enthusiasm of its author for the geologic story and the spirit of the Tetons. Even the layman can thoroughly appreciate the interesting general geology of the region, the structural building of the dominating range, and its later remarkable sculpturing, through the fascinating form in which the material is presented. Dr. Fryxell's chaste literary style has brought out the aesthetic side of scholarly science with rare success. This little volume properly belongs in the field of literature as well as of science.

R. T. C.

Outline of Historical Geology. By A. K. WELLS. London: Allen & Unwin, Ltd.; New York: Nordemann Publishing Co., 1938. Pp. xiv+266; figs. 99; pls. 2. $3.50.

This volume constitutes an excellent treatise on the stratigraphy of the British Isles. It outlines in detail the sequence of sedimentation from the Cambrian period to the Recent. It is profusely illustrated with drawings of structure sections, stratigraphic columns, and index fossils. Only a few photographs are included, however.

According to the Preface, the book is intended to appeal to the gen-

eral reader, "the man on the street," and the undergraduate with no geological background. As a matter of fact, however, the volume presupposes not only an appreciation of elementary geology but a knowledge of local British geography as well. Throughout the text may be found such words and phrases as "stipes" (p. 24), "feldspathic sandstones or arkoses" (p. 72), "coarse breccias, known as 'brockrams' . . . . the brockrams represent the piedmont gravel fans" (p. 132), "seat-earths" (p. 167), and "riebeckite-microgranite" (p. 237). Typical of phrases throughout the book is: "the lower Lias stretches southwards from the Mendips across the almost 'dead level' Sedgemoor, but the general monotonous flatness is relieved by the steep-sided Glastonbury Tor, and farther to the west by Brent Tor, while nearer to hand the hogbacked Polden Hills lie parallel to the Mendips" (p. 155).

Such a style requires a certain background in processes and principles of geology in addition to a knowledge of the local geography for ready appreciation by the reader. Index fossils are constantly referred to by specific name, the significance of which requires some knowledge of paleontology. The use of more photographs, rather than drawings, would have added to general reader appeal.

The volume as written would constitute an excellent textbook for a college course in British stratigraphy.

RAYMOND E. JANSSEN

The Principles of Soil Science. By ALEXIUS A. J. DE SIGMOND. London: Thomas Murby & Co., 1938. Pp. 362; pls. 4; figs. 34. *22s. 6d.* net.

De Sigmond is known in America chiefly for his studies on the reclamation of alkali soils, which have been published in English by the University of California. As professor of agricultural technology at the University of Technical Sciences in Budapest, however, he is regarded in European circles as an expert on all phases of soil science. *The Principles of Soil Science* was first published some time ago in Hungarian. In its original form it was an attempt at a comprehensive outline of all aspects of modern pedology. The material was divided into four parts: (1) "Genetics," the origin of soils; (2) "Agronomy," the physical, chemical, and biological properties of soils; (3) "Systematics," the classification of soils; and (4) "Cartography," the geographical distribution and mapping of soil types. In making the English translation, it seemed advisable to leave out not only many details of local interest but also the sections under "Agronomy" dealing with soil physics and soil microbiology, as these topics were already thoroughly covered in English soil literature. In its

present form, the book has for its main theme the presentation and discussion of the chemical system of soil classification already internationally known by the author's name, but never before described in detail in an English publication.

WILLIAM F. READ

Wissenschaftliche Ergebnisse der Niederländischen Expeditionen in den Karakorum und die angrenzenden Gebiete in den Jahren 1922, 1925, 1929/30 und 1935, Band II: *Glaziologie*. By PH. C. VISSER. Leiden: E. J. Brill, 1938. Pp. 216; figs. 98; tables 3; maps 3. 12 guilders.

The glaciers of the Karakoram Range of northwestern India lie in a region of great relief, high altitudes, strong insolation, and a continental climate. These conditions give them certain characteristics which are of importance in any study of glacier types; also, knowledge of the behavior of these large ice streams naturally contributes to the solution of various glacial problems. In this new volume is presented a study of the Karakoram glaciers, in part descriptive, but more particularly an analysis of their features and phenomena in the light of present-day knowledge and current theories.

One observed peculiarity is the prevalence of an "ablation gorge" between the steep side of a valley glacier and the near-by valley wall. This is due not to lessened feeding of the ice stream so that it no longer completely covers the floor of the valley but instead to melting of the marginal ice by reflected heat from the rocky valley side warmed under a subtropical sun in a relatively thin atmosphere. These "ablation gorges" occur below the snow line and mostly above 3,500 meters elevation. Ice pyramids and *sêracs* (up to 50 meters and more in height) are especially prominent on the surface of these low-latitude glaciers.

The behavior of certain tributary glaciers joining a main ice stream was found to be instructive. Agassiz, and others since his time, have believed that a glacier coming in from the side crowds the main glacier and continues alongside it downstream, maintaining its own integrity down to the valley floor. Doubtless this is true if the two glaciers have about the same size and velocity. But Visser found clear cases in the Karakorams in which a smaller and thinner tributary glacier overrode the larger ice mass and traveled superposed upon it down the valley until eventually the thin cover glacier was entirely removed by ablation and only the main glacier continued onward.

Especially careful consideration is given in this volume to the some-

what controversial questions of glacier motion, the development of blue bands, and the erosion of valleys by glaciers. Following their detailed treatment is a section giving factual information about the most important glaciers of the region.

R. T. C.

"Landslides in the Lysa Gorge and Their Importance in Laying Out Communications (Sesuvy v Lyskem Prusmyku a Jejich Vyznam pro Komunikacni Stavby)," by QUIDO ZARUBA-PFEFFERMANN, in *Technicky Obzor*, Vol. XLVI, Nos. 1–3. Praha, C.S.R., 1938.

With the recent revival of interest in landslides from both theoretical and practical viewpoints, English-speaking geologists should find much of value in studies being conducted by Dr. Zaruba. In the Carpathians of Moravia and Slovakia, as elsewhere in regions of moderate-to-high relief in eastern Europe, special difficulties are encountered in railroad construction where the bedrock is of the "Flysch" type—consisting of sandy to pure shales. But other rocks are affected as well. Movement is found by the author to take place in the clayey residual mantles, with great capacity for water adsorption. Highly detailed topographic maps were prepared, and these, together with other data, showed that there are surface slides not unlike those of the terminal and ground moraine belts in the middle western states of the United States. Two types of slides are recognized, "shallow surface slides" and "stream slides."

These general conclusions are followed by a detailed description of three very remarkable slides of the "stream" type, the most striking being the great Dubkova slide. This resembled somewhat the landslide at Thunder Mountain ("Roosevelt"), central Idaho. It was a mud flow, advancing like a great slow wave, concentrated in about one day's time, and following a heavy thaw and rainfall. The track of the slide was 1,050 yards long. Its upper edge is marked by a scarp scar 60 feet high. An interesting feature is the production of pseudoglacial phenomena ("lateral moraines," furrows in the soft material of the adjacent banks, and a U-shaped cross section of the valley resulting from the slide). To one familiar with rock-slide topography in Alpine altitudes, parts of the description are highly suggestive.

As is usually the case with scientific publications emanating from Czechoslovakia, the study is published in two languages, Czech and another—in this case English.

CHARLES H. BEHRE, JR.

"Structural Petrology," by E. B. KNOPF and EARL INGERSON. *Geological Society of America Memoir 6.* Washington, D.C., 1938. Pp. 270; pls. 27; figs. 81.

With the publication of this memoir the content of Sander's *Gefügekunde* and the methods of petrofabric analysis become more completely accessible to English-speaking workers than ever before. Beginning students and investigators in other fields will turn for guidance to this well-written and admirably illustrated treatise and will not be disappointed. To those familiar with the field of structural petrology, however, a number of criticisms immediately suggest themselves. This reviewer for one had expected the authors to cover a much wider field and to discuss certain controversial topics which are uppermost in the minds of many of us. After reading the entire text and noting its commendable objectivity, I turned back to the Preface, hoping to find some explanation of the authors' self-imposed limitation of topics. Discovering none, it is therefore somewhat disconcerting, in the year 1938, in a memoir entitled "Structural Petrology," to find not even a footnote concerning the work of Balk and the Cloos brothers, and scant mention of the pioneer investigations of Van Hise, Leith, and their students. Disagreement with another's conclusions is to be welcomed in any discussion; complete disregard of their existence is questionable science. The cause of structural petrology is not advanced through avoiding discussion of controversial points, and the present memoir would serve its purpose much more fully if these problems had received an airing.

The field and laboratory investigations described in the text are also curiously selective in a memoir of this size. Schmidegg's work in the eastern Alps, Clar's and Ladurner's studies of metasomatic replacement, and Closs's and Osborne's investigations should have been mentioned at least by title. Criticism of the terms "axial-plane foliation" and "bedding cleavage" is made without giving the reader the benefit of a reference for further study of the problem. Indeed so few references to American structural problems are made that the uninitiated might easily gain the impression that structural petrology had rendered structural geology quite unnecessary.

The presentation in geologic literature of gliding and preferred orientation in metals is to be welcomed, if only to show the paucity of similar data for rock minerals. The detailed classification of symmetry of movement is perhaps less useful at present, although the conception is highly important. The authors (and I am not blameless in this regard) have also to a certain extent become the slaves of terminology through too

rigid adherence to the text of *Gefügekunde*. In a word-burdened world simplification is desirable. Many of the English equivalents, however, are happily chosen, such as, "axial symmetry" for "wirtelige Symmetrie," "componental movement" for "Teilbewegung," and "collective diagram" for "Sammeldiagramm." I question the advisability of using "precrystalline," "postcrystalline," and "paracrystalline" instead of the more cumbersome "precrystallization," etc.

In the section on methods of analysis one looks in vain for any mention of X-ray technique. Likewise the advantages of the Emmons five-axis stage for measurement of biaxial minerals do not receive consideration. It is also debatable whether the average petrofabric examination warrants the great detail prescribed for orienting specimens.

The good qualities of the book—readability, arrangement, and illustration—are a credit both to the authors and to the publishers, and it is deserving of wide circulation.

H. W. FAIRBAIRN

Studies in Earth Movements. By R. G. LEWIS. London: R. G. Lewis, 1937. Pp. 173.

One is amazed at the amount of geomorphologic evidence in support of the undulation hypothesis that R. Gulley Lewis has assembled in *Earth Movements*. River terraces, raised beaches, kitchen middens, historical records, varved glacial deposits, and glaciology are called upon to furnish evidence for wave trains crossing Europe in Pleistocene time.

Mr. Lewis has made a masterful case for undulations marching across country by his use of beaches and river terraces. He has correlated terraces and beaches from one part of Europe to another and has shown that beaches of the same age are not everywhere at the same elevation. He says that many of the irregularities may be explained if one accepts the idea of a train of waves moving out from a foundered portion of the surface.

As another possible causal mechanism, he suggests (p. 43) convection currents rising from depth in hypothecated fluid layers and setting up a series of waves (cf. Arthur Holmes). It may be questioned whether the forces which might thus be postulated are greater than those which he claims are inadequate to produce movements according to Joly's hypothesis of thermal cycles.

The reviewer most wholeheartedly recommends Mr. Lewis' book as an extremely thought-provoking summary of the evidence supporting the undulation hypothesis. Any geologist interested in problems of diastro-

phism will find the book well worth his while. It is so simply written that those with a minimum of geological training may read it with profit. The closing chapters, in which are sketched the need for a hypothesis of plastic flow and are suggested lines of future investigation, are particularly intriguing.

H. W. STRALEY, III

"Problematica Verrucana. Tavole iconografiche delle vestigia vegetali, animali, fisiche e mecaniche del Wealdiano dei Monti Pisani," by A. FUCINI, *Palaeontographica italica*. Pisa, 1937–38. Pp. 258; pls. xii + 152.

Since the time of Murchison and Sedgwick one of the greatest and most unexpected advances in European stratigraphy is the statement made by the author that the so-called "Verrucano" of the Monti Pisani in Tuscany, Italy, is of Lower Cretaceous instead of Permian age. Nearly the whole succession of strata in the western Mediterranean (Hesperian) region has been greatly modified by this discovery.

In those hills and in many places in the Apennines the substructure of older rocks is intensely folded, fractured, and only preserved as ruins of a large mountainous range, which, as the continuation of the western (Hesperian) Alps, occupied Italy and a great part of the western Mediterranean in pre-Cretaceous time (southern Hesperian Alps). There the "Verrucano" is a covering of the substructure.

Without having noticed the unconformity between the plant-bearing Permian beds (Autunian) and that "Verrucano," the latter was called Permian. It is a coarse detrital quartzitic deposit—boulders, gravels, breccia, siliceous schists, quartzite, and jaspers—of ferruginous color, the residue of the underlying schists rich with siliceous dikes and nodules. There Fucini found in some strata an enormous amount of "Problematica" of different kinds—perhaps the richest locality for these types. Besides, there occurs a poor fauna of fresh water and brackish shells which was determined as being of Lower Cretaceous (Wealdean) age. Also, hundreds of footprints of reptiles and amphibians were found, but no trace of bone.

Besides these animals there occur many plant impressions, to a great extent very dubious ones, which show the unique feature of being quite devoid of carbon. Therefore, most paleobotanists will not admit their vegetal origin. But the lithological conditions of that locality seem to be exceptional.

The first part of the work gives besides the description of imprints of

recent origin and besides other algal(?) forms the reproduction of a stellular (algal?) type, which has been given the name of Sewardiella. This has been much questioned by the reviewers. Only one specimen of it has been found in Solenhofen.

The second part brings among other plantlike remains a discovery of great importance, viz., the determination of many imprints of the bark of conifers, especially of pine trees. Some of them show likeness to specimens of Sequoia from Spetsberg.

The next part will figure the animal traces, especially the footprints and mechanical effects on the soft mud of the shallow Lower Cretaceous sea.

The monograph is and will be for a long time the most important of its kind and surely will arouse an interest for such "Problematica" found, but little regarded, in all collections.

F. X. SCHAFFER

"Fossil Flora of Sydney Coalfield, Nova Scotia," by W. A. BELL. *Canada Department of Mines and Resources, Geological Survey Memoir 215*. Ottawa, 1938. Pp. 334; pls. 107; pocket charts 2. $0.75.

The "Fossil Flora of the Sydney Coalfield" constitutes a monograph based on a large collection of plant specimens obtained from the Morien beds of Westphalian age in Cape Breton Island. The assemblage, obtained from several hundred localities, contains about 125 species, of which 18 are considered to be new. It is of unusual interest to note that *Lonchopteris* (an alethopteroid form characterized by reticulate veination) has now been recorded for the first time from the Pennsylvanian of North America. Heretofore it was known in this continent only in Mesozoic strata.

On the basis of the distribution of its included fossils, the Morien series has been divided into three zones, designated by the author, from bottom to top, as (1) zone of *Lonchopteris eschweileriana* and *Alethopteris lonchitica*, (2) zone of *Linopteris obliqua*, and (3) zone of *Ptychocarpus unitus*. Although considerable overlapping of species occurs, as might be expected, the differentiation of the flora into these zones appears to be well justified.

The monograph is profusely illustrated with cuts of good quality, and a pocket at the back of the volume contains charts which show the vertical range of the various species. This work constitutes a notable contribution to our knowledge of Carboniferous paleobotany.

RAYMOND E. JANSSEN

Geology of the Province of Camaguey, Cuba, with Revisional Studies in Rudist Paleontology. By H. J. MacGillavry. ("Physiographisch-Geologische Reeks," No. 14.) Utrecht: Geographische en Geologische Mededeelingen, 1937. Pp. 168; pls. 10; maps 1.

Dr. MacGillavry was a member of an expedition from the University of Utrecht which, in 1933, spent twelve days making a reconnaissance geological study of the province of Camaguey. Cretaceous and Eocene marine sediments were found to be intruded by igneous masses of similar age. A rough areal map accompanies the report.

The second part of this publication, which dealt with rudist paleontology, is the more notable contribution. Rudists were found to be an important element in the paleontological collections made by the expedition in various parts of Cuba. Although some of this material had already been described in earlier reports, Dr. MacGillavry considered it advisable to assemble the whole of it for further study. The rudist collections are here treated by him in almost monographic fashion. The main purport of his paper is a revision of the classification of inverse rudists. Formerly they have been divided into two subfamilies, the Glyptopleurinae and the Monopleurinae. Here they are ranged in three groups: (1) the radiolitid type; (2) the trachmanellid type; (3) the caprinid type. The reader is referred to other sources for a full discussion of the radiolitid type, but the other two types are treated here in elaborate detail. The annotated bibliographies of each genus should be useful to paleontologists interested in this group.

WILLIAM F. READ

Les Mégaspores du Bassin Houiller Polonais, Part II. By JAN ZERNDT. ("Académie Polonaise des Sciences et des Lettres, Travaux Géologiques," No. 3.) Kraków, 1937. Pp. 78; pls. 24; figs. 82.

This publication is the second volume of a series describing the megaspores occurring in the strata of the Polish Coal Basin. The first volume of the series was issued in 1934. Forty-five varieties of spores are described, the majority of which belong to the genus *Triletes*. In addition to a systematic description of the numerous forms, the spores are considered in assemblages according to their occurrences in each of fifty mines located throughout the coal basin. Fifty tables and thirty-two charts show the relative abundance of each spore species occurring in the respective mining localities. Photomicrographs, showing the several forms enlarged from fifty to one hundred diameters, picture the various characters in excellent detail.

As a result of this work, it has become possible to correlate beds occurring in one part of the Polish Basin with any other part, or to determine the horizon of any bed by isolating spores from a relatively small sample of matrix.

RAYMOND E. JANSSEN

"Spores from the Herrin (No. 6) Coal Bed in Illinois," by JAMES M. SCHOPF. *Illinois Geological Survey Report of Investigations, No. 50.* Urbana, 1938. Pp. 73; pls. 8; figs. 2.

This publication consists of a description and classification of fossil plant spores obtained from the Herrin (No. 6) coal bed—a bed of commercial importance in Illinois. Twenty varieties of spores have been considered, most of them belonging to lycopods. Existing classifications have been emended, two new genera have been established, and eight new species described.

RAYMOND E. JANSSEN

"The Yukon-Tanana Region, Alaska," by J. B. MERTIE, in *U.S. Geological Survey Bulletin 872.* Washington, D.C., 1937. Pp. 276; pls. 15; figs. 2. 70 cents.

The Yukon-Tanana region is an area about as large as Indiana located in east-central Alaska. For more than thirty-five years geologic investigations, mostly of a reconnaissance nature, have been going on in this district. Enough is now known to justify the preparation, for this bulletin, of a summary report on the general and economic geology, accompanied by an areal geologic map on the scale of eight miles to an inch. In the sedimentary sequence nearly every period from the Cambrian to the Quaternary is represented. The pre-Cambrian is exposed over wide areas. Each recognized formational unit is discussed with reference to its distribution, lithology, structure, and age. Faunal check lists are provided. The bedded igneous rocks are treated with the sedimentaries. The massive igneous rocks are split into several groups representing as many major cycles of injection. Each group is examined separately with reference to distribution, petrographic character, and structural relationships. Finally, the major sequence of events recorded by all the different kinds of rocks is summed up in a (necessarily) much-abbreviated geologic history.

The economic geology is treated in its broader aspects only. An attempt is made to link the origin of known ore deposits with certain specific

processes or events in the geologic record, and thus to provide an intelligent basis for future exploration and development.

This report also includes a brief résumé of the geography, climate, vegetation, etc. It is amply illustrated with photographs.

WILLIAM F. READ

"Postglacial Changes of Shoreline in South Finland," by ESA HYYPPÄ, in *Commission Géologique de Finlande Bulletin 120*. Helsinki: Suomen Geologinen Toimikunta, 1937. Pp. 225; figs. 57; tables 21; pls. 2.

Since 1931 Dr. Hyyppä has been investigating the problem of postglacial changes of sea-level in South Finland. The present paper sums up his discoveries and conclusions to date. In this region it is impossible to trace the old beaches topographically for more than short distances. But widely separated remnants of once continuous beaches may be correlated on paleontological grounds. The indices used for this purpose are pollen grains and diatoms found in the sediments which were laid down while the ancient beaches were forming. Such deposits have escaped removal by erosion where they were laid down in some sort of depression. These depressions are now usually occupied by bogs.

In a region of oscillating shorelines it is obvious that the sediments contained in a depression near the coast may have continued to accumulate while the depression stood above, below, or at shore-level. It is the diatoms that give the clue to conditions of deposition, for a diatom assemblage reflects the size, depth, and salinity of the body of water in which it lived. The pollens serve to date a particular horizon in reference to the known sequence of postglacial forests. Thus the pollens are used to correlate between deposits which are known, from the diatom content, to have formed under shoreline conditions, and, in this manner, the positions of successive shorelines may be worked out.

Numerous samples from some thirty-five "bogs" provide the data for this paper. After all the paleontological evidence has been presented in the form of graphs and tables, the inferred succession of shorelines is shown on what is called a "relations diagram." This is a diagrammatic cross section along some convenient line of reference showing the old shorelines as straight or bent lines variously disposed in relation to the present sea-level. The relations diagram forms the basis for a general discussion of the postglacial record in South Finland and its relationship to the known record of the Baltic region as a whole.

WILLIAM F. READ

Northernmost Labrador Mapped from the Air. By ALEXANDER FORBES, with contributions by O. M. MILLER, N. E. ODELL, and ERNST C. ABBE. Spec. Pub. 22. New York: American Geographical Society, 1938. Pp. 255; figs. 177; maps 6.

The American Geographical Society presents with this publication four topographic maps covering the coast of Labrador for 120 miles southeastward from its northernmost extremity at Cape Chidley. As a result of expeditions made under the direction of Dr. Forbes of the Harvard Medical School in 1931, 1932, and 1935, the topography is now accurately known for some 15 or 20 miles inland. The maps are drawn to a scale of about 1½ miles to the inch (1:100,000) with a contour interval of 50 feet, which is quite sufficient to represent the bold relief of this area. There are two additional maps: one, an outline chart showing the distribution of survey control points; and the other, a composite generalized relief map of the whole area on a scale of 5 miles to the inch.

Dr. Forbes in his paper recounts the story of the three expeditions. Many splendid aerial panoramas and other photographs illumine his narrative. Mr. Miller, of the American Geographical Society, describes the unusual techniques employed in constructing topographic maps from oblique aerial photographs—techniques which he has himself perfected. Noel E. Odell of Cambridge University and Ernst C. Abbe of the Grey Herbarium accompanied the expedition of 1931 in the capacities of geologist and botanist, respectively. The detailed results of their investigations have already been published elsewhere; but their findings are, in somewhat condensed form, restated here.

WILLIAM F. READ

My Last Expedition to the Antarctic, 1936–1937. By LARS CHRISTENSEN. Oslo: Johan Grundt Tanum, 1938. Pp. 16; photographs 26; maps 4.

This booklet constitutes a lecture delivered before the Norwegian Geographical Society on September 22, 1937, describing an exploration trip and aerial survey along the coast of Antarctica. Included also is a brief summary of research work accomplished during the author's previous expeditions of 1927–34. Numerous aerial photographs and maps contrasting geographical knowledge of Antarctica in 1927 with that of 1937 add to the attractiveness of the publication, which is printed in English.

RAYMOND E. JANSSEN

"Origin of the Cap Rock of Louisiana Salt Domes," by RALPH E. TAYLOR. *Louisiana Geological Survey, Bulletin 11.* New Orleans, 1938. Pp. xiv+191; pls. 26; figs. 4; pocket map 1.

The origin of the cap rock which forms mantles of varying thicknesses directly overlying most of the known salt domes is here made the subject of detailed investigation. Cap rock is not known to be missing absolutely from any salt dome, for, in cases where it is not reported, exploration has not been complete.

Because of its complexity, cap rock cannot be divided satisfactorily into any series of continuous beds or layers. Three fairly well-defined zones can be distinguished where the cap rock is well developed, however, the most important of these being the lowermost zone adjacent to the salt, in which anhydrite predominates. The upper part of the thicker and better-developed cap rocks consists of a calcite zone. Between these is a transition zone containing, in addition to anhydrite and calcite, most of the sulphur, gypsum, and other cap-rock minerals.

It has been found that the anhydrite in the cap rock is identical with that in the salt and different from that of primary, bedded deposits; that the minerals of the salt residues can be traced into the overlying cap; and that the development of the cap rock is progressive by means of alteration and residual accumulation of the less soluble constituents from the associated salt. Petrographic evidence indicates that the rock of the transition and calcite zones has been formed by alteration of the anhydrite. Although formed essentially in place, the cap rock may be later affected by further upward movement of the salt plug.

The volume contains tables showing the mineral constituents and percentages of relatively insoluble residues from the various salt domes studied. Two appendixes deal with the economic geology and description of cap-rock well cores. A pocket map, showing the locations of all salt domes in Louisiana, and numerous photomicrographs of thin sections add appreciably to the value of the work. The author has presented a worthy contribution in support of the residual-accumulation theory of cap-rock origin as first suggested by Hanna and Goldman.

RAYMOND E. JANSSEN

"Origin of the Shoestring Sands of Greenwood and Butler Counties, Kansas," by N. WOOD BASS, in *State Geological Survey of Kansas Bulletin 23.* Lawrence, Kan., 1936. Pp. 135; pls. 21; figs. 10.

In southeastern Kansas, oil-bearing "shoestring sands" occur at a depth of about 2,000 feet in Pennsylvanian shale. Extensive drilling oper-

ations during the last fifteen years have supplied sufficient information about these peculiar structures to justify certain tentative conclusions regarding their origin. It seems probable that the shoestring sands are portions of several series of buried barrier beaches, which once fringed an oscillating seashore. The shape of individual lenses—flat below and convex above—makes a river-channel origin seem unlikely. The peculiar alinement of series of lenses along more or less continuous "trends" strongly suggests the arrangement of sandbars along modern shorelines. Mr. Bass marshals the evidence supporting this hypothesis in convincing fashion. His "frame-work" block diagrams, constructed from well logs, show the barlike proportions of individual lenses. A large pocket map shows the trend arrangement. Finally, alined, and presumably contemporaneous, series of the shoestring sands are diagramed against backgrounds of coastal marshland representing the conditions supposed to have existed in Pennsylvanian time.

A considerable portion of this bulletin, not suggested by the title, is composed of material which has no immediate bearing on the problem of the origin of the shoestring sands. Nearly a third of it is a general summary of stratigraphic relations in the shoestring area. In addition, a number of pages are devoted to a report on very detailed mapping work undertaken to discover whether there was any reflection of the buried sands in surface structures. The results of this study were negative.

WILLIAM F. READ

"Geology and Natural Resources of West Virginia," by PAUL H. PRICE, R. C. TUCKER, and O. L. HAUGHT. *West Virginia Geological Survey*, Volume X. Morgantown, 1938. Pp. 462; figs. 61; pls. 231.

This volume was prepared by the West Virginia Geological Survey to provide a general summary of the state's geology and mineral resources. It begins with a description of physiography, climate, native vegetation, etc. Then, by way of introduction to the geology, some hundred pages are devoted to explaining geologic processes and the principles of historical geology. In this connection, the formation of coal, an important resource, is discussed at considerable length. Finally, the actual stratigraphy and structure, as revealing the geologic history of the state, are taken up. Characteristic fossils from each formation are figured, together with photographs showing typical exposures and other features of interest. No sedimentary formations younger than Paleozoic are found in this state.

In the section on mineral resources, each formation is again discussed

from the viewpoint of its economic importance. This method of approach serves to integrate the economic with regional geology. Having made clear this relationship, the authors proceed to discuss each type of mineral product separately. The volume is splendidly illustrated and fully indexed in a manner designed to make it a handbook of ready reference for laymen as well as trained geologists. A geologic sketch map of the state in black and white is included.

WILLIAM F. READ